Geologic and Seismclogic Investigation

DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

BEST AVAILABLE COPY

US Army Corps
of Engineers
Sacramento District

DECEMBER 1988

BEST AVAILABLE COPY

..., Corps of Engineers, Sacramento District
Technical Library
1325 J Street, Suite 820
Sacramento CA 95814-2292

SUBJECT: Submission of Technical Reports for inclusion in Technical Reports Database

The enclosed documents are hereby submitted for inclusion in DTIC's technical reports database. The following is a list of documents included in this shipment.

1. Little Dell Lake, Salt Lake City Streams, Utah, Embankment Criteria and Performance Report, August 1994
2. Caliente Creek Stream Group Investigation California, Draft Feasibility Report, June 1987
3. Fanchier Creek Dam Fresno, California, Embankment Criteria and Performance Report, July 1994
4. Sacramento Metropolitan Area California: Final Feasibility Report and Final Environmental Impact Statement/Final Environmental Impact Report, February 1992
5. Geologic and Seismologic Investigation, Hidden and Buchanan Dams, Hensley Lake and Eastman Lake, Fresno and Chowchilla Rivers, California, December 1988
6. Sacramento River Flood Control Project, California, Mid-Valley Area, Phase III, Design Memorandum, Volumes 1 and 2, August 1995
7. Reconnaissance Report Yolo Bypass, California, March 1992
8. Provo and Vicinity, Utah, General Investigation Reconnaissance Report, April 1997
9. Sacramento-San Joaquin Delta, California, Draft Feasibility Report and Draft Environmental Impact Statement, October 1982

The **distribution statement is A** approved for public release; distribution is unlimited.

The Sacramento District source code is <u>410637</u>. Please return any materials that aren't appropriate for the technical reports database. Mailing label enclosed.

If you need assistance, please contact the undersigned at 916-557-6660.

Frances J Sweeney
Sacramento District Technical Library
Frances.J.Sweeney@usace.army.mil

5 FAULTS: EXISTING, POSTULATED OR INFERRED

6 INVESTIGATIONS

FIGURES

TABLES

APPENDIXES

INDEX OF SHEETS

PLATES

GENERAL: As a result of the Dam Safety Assurance Program (DSAP), all dams constructed by the United States Army Corps of Engineers are being reviewed to determine their performance based on current state-of-the-art in civil engineering design and hydrology. Among the parameters included is the reaction of each dam and its appurtenances to seismic loading.

The seismic design parameters of Federal water projects constructed in and along the eastern Sacramento-San Joaquin Valleys and the western Sierra Nevada Foothill region of California are of particular interest due to the occurrence of the August 1, 1975 Oroville, California 5.7 Richter magnitude earthquake and ground rupture. This earthquake occurred on the Foothills fault system, which may extend through the Sierran foothills from east of Red Bluff in the north to as far south as Porterville, California. Hidden and Buchanan Dams are located within 31 miles (50 km) and 22 miles (35 km) respectively of the mapped southern termini of the Melones and the Bear Mountains fault zones, which are major constituents of the Foothills fault system.

Geologic evaluation of Quaternary age stratigraphy such as exists in the Hidden and Buchanan Dams study area was used to ascertain whether faults in the area have undergone movement within the last 35,000 years. Any movement since this time frame would necessitate considering such faults as being capable of producing future earthquakes.

LOCATION: Hidden and Buchanan Dams (Hensley and Eastman Lakes) are located along the southeastern margin of the San Joaquin Valley and the western Sierra Nevada foothills. This area forms the boundary between the Great Valley and the Sierra Nevada geomorphic provinces. The dams are centrally located in the 1,750 square-mile (4,533 square km) study area with Hidden Dam about 15 miles (24 km) northeast of the town of Madera, California and Buchanan Dam about 16 miles (26 km) northeast of the town of Chowchilla, California. The construction of these projects was completed in 1975.

INVESTIGATIONS: Office and field investigations concentrated on all known faulting within the area, with special emphasis given to any faults or structural features listed as Quaternary or younger in age. A photogeologic interpretation and imagery analysis was accomplished using SLAR, Skylab (1973) color infrared (CIR), EROS CIR, and National High Altitude Photography, black and white imagery. This resulted in the compilation of a photolineament and

Quaternary geologic map. This map was then field checked and six sites were chosen for subsurface investigations.

The photolineament and field investigations at Sites 1, 3, and 5 revealed the following:

1. The primary photolineament set has a regional trend of N20°W to N50°W, similar to the strikes of the Tertiary Ione, Valley Springs, Mehrten, and Laguna Formations.

2. These photolineaments generally conform to topographic lows, such as aligned swales and linear valleys.

3. Trench excavations across the photolineaments found no evidence of faulting.

4. Trench logs indicate the photolineaments are the result of fluvial processes, possibly influenced by regional joint sets reflected in the Tertiary and Quaternary formations from underlying bedrock (PG&E, 1977).

5. Undisturbed Quaternary formations overly the photolineaments detected by the imagery analysis which indicates there has been no tectonic movement from about 100,000 to 400,000 years ago to the present.

The field investigations of features incorrectly inferred as faults at Sites 2, 4, and 6 revealed the following:

1. The inferred faults mapped as existing at Sites 2 and 6 had a similar regional trend to the photolineaments. The inferred and queried fault mapped as existing at Site 4 did not.

2. The inferred fault at Site 2 and the inferred and queried fault at Site 4 were located on topographic highs or hilltops. The inferred fault at Site 6 was located in a topographic low or swale.

3. No fault exists at Site 2. Fluvial processes account for the apparent discontinuous bedding visible in the roadcut on Avenue 15.

4. No fault was located at Site 4 along Avenue 24. The Quaternary formations overlying the site are not displaced. Some of the layers do exhibit localized cracks or possibly what was referred to as joints in trench excavations conducted for PG&E (1977) and these cracks often weather unevenly and may be what Marchand and Allwardt (1978) saw when inferring a fault at this site.

5. No fault was located at Site 6 in the Quaternary sediments or in the underlying bedrock.

CONCLUSIONS:

1. No capable faults were found within the geologic and seismologic investigation area for Hidden and Buchanan Dams .

2. Subsurface investigations performed in this study found no evidence to substantiate the existence of three inferred faults mapped by Marchand (1976a,b,d and 1978) and Marchand and Allwardt (1981).

3. The San Andreas fault system and the Sierran Frontal (Owens Valley) fault system are the most likely sources of seismic events which will have the greatest felt intensities at Hidden and Buchanan Dams.

4. A hypothesized M 6.5 event on the Foothills fault system at approximately 31 miles (50 km) and 22 miles (35 km) from Hidden and Buchanan Dams, respectively, and a random M 5.0 event at a distance of 6.2 miles (10 km) from each dam should be evaluated to determine whether or not these base rock motions would exceed the seismic design criteria for the maximum credible earthquake which could occur on either the San Andreas fault system or the Sierran Frontal fault system.

5. The seismic design criteria for the maximum design earthquake should be scaled from regionally similar accelerograms selected by a recognized authority in California seismology.

1 INTRODUCTION

1.1 Authority. Earthquake risk and seismic hazard studies are authorized under ER 1110-2-1806, dated 16 May 1983.

1.2 Purpose. Pursuant to the Dam Safety Assurance Program (DSAP), all dams constructed by the U.S. Army Corps of Engineers are being investigated to determine their performance based on current state-of-the-art in civil engineering design and hydrology. Among the parameters included in this review is the reaction of each of the dams and their appurtenances to seismic loading. This report documents the results of the geologic and seismologic investigation for Hidden and Buchanan Dams and the impact on the safety and stability of each of these projects.

1.3 Previous Studies. Responding to DSAP, the Sacramento District (SPK), performed extensive literature research, geologic reconnaissance studies, and reconnaissance-level field mapping of the Hidden and Buchanan Dams study area in April 1985. The literature search revealed at least three major sources of data had been published since construction of the dams and these contain information on the identification and the location of faults and lineaments within the study area. These data sources are listed below:

1. Pacific Gas and Electric Company (1977) for the proposed Madera and Merced Nuclear Power Plants. Included in the report were numerous locations of photolineaments mapped within the study area and the results of trench investigations excavated across many of the photolineaments.

2. Reports and maps prepared by Marchand (1976a-f, 1977) and Marchand and Allwardt (1978, 1981) for the U.S. Geological Survey delineating the Quaternary formations within the

study area, and showing lineaments and several short inferred faults which were not investigated by PG&E (1977).

3. A preliminary photolineament map developed by Hodges (1979) for the U.S. Geological Survey from Landsat images and U-2 photography, covering the study area.

Subsequently, SPK prepared two reports entitled "Geologic Reconnaissance of the Hidden Dam and Hensley Lake Area, Madera County, California", and "Geologic Reconnaissance of the Buchanan Dam and Eastman Lake, Madera County, California." These reports recommended that a regional fault study be conducted to determine the presence, extent, and capability of faults within the area.

1.4 Scope. The scope of the geologic and seismologic investigation for Hidden and Buchanan Dams included the following:

1. Locate geologic-topographic features within the study area which might have resulted from faulting.

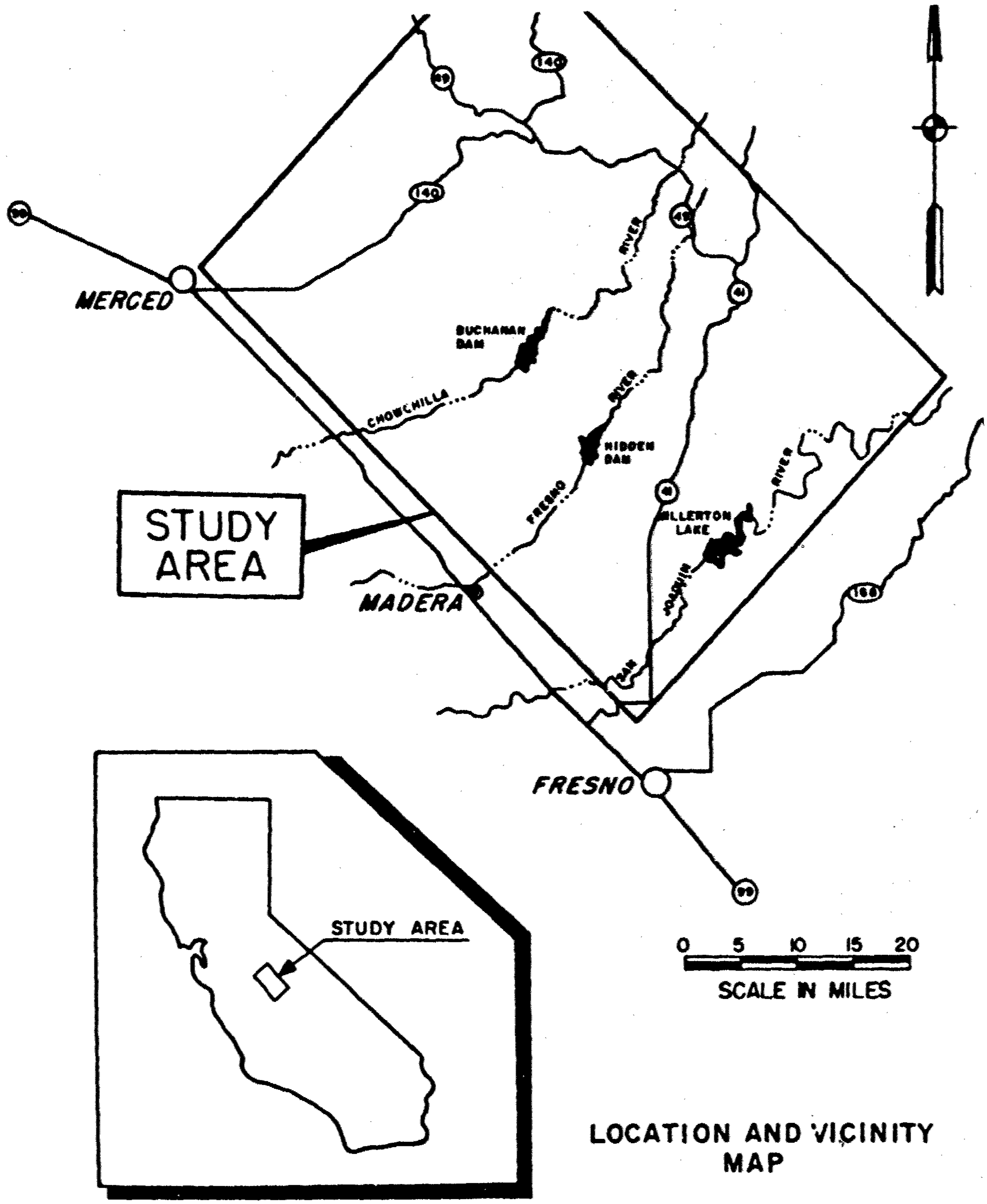
2. Investigate the identified features.

3. Determine whether or not the features represent capable faults as defined by Corps of Engineers criteria (ETL 1110-2-301, dated 26 August 1983), which are characterized by movement within the last 35,000 years.

4. Provide guidance in developing seismic parameters for use in dynamic response analyses for the dams.

5. Prepare a report detailing the investigations and the findings.

1.5 Investigation and Performance: The study area (see Project Vicinity Map, Figure 1-1) covers approximately 1,750 square miles



LOCATION AND VICINITY MAP

FIGURE 1-1

(4533 square kilometers) east of Merced and Madera, California in the central portion of the San Joaquin Valley and the Sierra Nevada foothills.

1.5.1 Photogeologic Interpretation and Imagery Analysis, Hidden and Buchanan Dams: Early in 1987, SPK developed a detailed and specific scope of work for a photogeologic interpretation and imagery analysis contract for the Hidden and Buchanan Dams study area. A request for a proposal contract was advertised and subsequently awarded to the geotechnical firm of Harlan Miller Tait Associates (HMT), of San Francisco, California. The firm was tasked with the following:

1. Research, review, and acquisition of available data pertaining to geology, previously mapped lineaments, and the basis for published faults.

2. Research, review, and acquisition of available geophysical data pertaining to the area.

3. Review, acquisition, and analysis of pertinent aerial photography to be used in mapping all lineaments in the study area.

4. Compilation of bedrock and Quaternary geologic data.

5. Development of a geologic and lineament map in color.

6. Evaluation and recommendations for trenching locations based on the imagery analysis and geologic mapping.

7. Preparation of a report discussing the findings of the study.

Harlan Miller Tait, as proposed, subcontracted with Photographic Interpretation Corporation (PIC) of Lyme, New Hampshire to do the initial photogeologic interpretation and lineament location. That work was then field reviewed and refined by Robert H. Wright, PhD.

(HMT) using published and unpublished mapping developed by Marchand (1976a-f), and Marchand and Allwardt (1978) of the U.S. Geological Survey, Menlo Park, California. Also subcontracted was Roy J. Shlemon, PhD. of Newport Beach, California for the evaluation of the distribution and age of Quaternary deposits. HMT conducted field work during May through July of 1987 and presented the Corps of Engineers with a draft report of the results in early August 1987.

1.5.2 Field Investigations and Report Preparation: In September 1987, the Corps of Engineers began backhoe excavations of five trench sites and debris removal along one roadcut at the locations recommended by HMT. Corps of Engineers geologists Thomas W. Fea, Kim E. Jorgensen, John J. Gewerth and Randy S. Adams performed the detailed logging of the excavated sites and the report preparation. Office administration, guidance, procedure, and report review was provided by Robert L. Treat and Millard D. Boyd. Roy J. Shlemon, PhD. was contracted to review the soil-stratigraphic/geomorphic age relationships observed in the trench investigations. Field investigations were completed in December 1987.

Additional guidance, opinions and on-site review of the study area and geologic conditions were provided by professional peers, Messrs. Alan L. O'Neill and Lawrence B. James. Their suggestions and contributions to this study are gratefully acknowledged.

1.6 Project Descriptions, Hidden and Buchanan Dams. See Location and Vicinity Map, Figure 1-1.

1.6.1 Hidden Dam. Hidden Dam is located on the Fresno River approximately 15 miles (24 kilometers (km)) northeast of Madera, California. The main dam is of rolled earthfill construction with a vertical chimney drain and connecting horizontal drain blankets. The dam is 184 feet (56 meters (m)) high and 5,730 feet (1746 m) long at the crest. The spillway consists of an unlined channel with a concrete broadcrested control sill. The project has six rolled earthfill dikes ranging in height from 7 to 40 feet (2.1 to

cover conduit, and a return channel. Construction was completed in 1975.

1.6.2 Buchanan Dam. Buchanan Dam is located on the Chowchilla River approximately 16 miles (26 km) northeast of Chowchilla, California. The main dam is a zoned rockfill structure with an impervious core. The dam is 218.5 feet (66.6 m) high and 1,800 feet (548.6 m) long at the crest. The spillway is an unlined trapezoidal channel with an ungated concrete control sill. The project has five earthfill dikes which vary in height from about 4 to 34 feet (1.2 to 10.4 m) and in length from 90 to 605 feet (27.4 to 184.4 m). The outlet works consist of an approach channel, a reinforced concrete cut-and-cover conduit, and a return channel. Construction was completed in 1975.

2.1 General: The southwestern Sierra Nevada bedrock complex consists of a chaotic assemblage of metamorphosed Paleozoic and Mesozoic eugeosynclinal rocks, which have been intruded by the Mesozoic plutonic rocks of the Sierra Nevada batholith. The Mesozoic eugeosynclinal metamorphic rocks (originally ocean floor sediments) were juxtaposed against Paleozoic age continental terrane during the convergence of the Farallon and North American plates (Atwater, 1970). This convergence occurred during the Nevadan orogeny along a "wrench zone" that cut obliquely into western North America and which, in the northwestern part of this study area, Saleeby (1975, 1977) believes is expressed as the Melones and Bear Mountains fault zones of the Foothills fault system.

As a result of the Nevadan orogeny, in Jurassic and Triassic time the eugeosynclinal rocks were metamorphosed, compressed into a series of folded mountains, and then faulted. The remnants of these rocks now exist as stratified metasedimentary and metavolcanic rocks whose major and minor folds have axial planes and parallel schistosities which trend N.15°W. to N.40°W. Subsequent uplift and erosion stripped away most of the metamorphic rock except for two long narrow belts flanking the western and eastern sides of the Sierra Nevada batholith and scattered roof pendants in the central portions. The westernmost of these belts lies within the study area and is generally referred to as the Western Metamorphic Belt. Latitude 37°30' marks the approximate southern termination of this 200-mile-long (322 km) by 30-mile-wide (48 km) Western Metamorphic Belt and the associated Foothills fault system.

2.2 Cretaceous-Cenozoic Tectonic Activity: The tectonic evolution of California and western North America is far from being completely understood. The following is a generalized chronological description of the tectonic activity spanning from

2.2.1 Cretaceous-Paleogene: During a span of about 120 million years, starting in Cretaceous and extending through Oligocene time, the Farallon and the American plates were converging, with the Farallon plate being subducted eastward beneath the American plate (Atwater, 1970). At the same time, batholithic masses were intruding and cooling at depth, becoming the ancestral Sierran volcano-plutonic arc. Isostatic adjustments, together with regional tectonic forces, were contemporaneously producing a westward tilting of the Sierran block (Wong and Savage, 1983, include the San Joaquin Valley in the Sierran block). This resulted in extensive erosion in the Sierra Nevada and caused corresponding deposition into the San Joaquin Valley.

By the end of Cretaceous time the Sierran block had become more stable with only minor deformation and tilting. Regional stresses were producing east-west compressive forces only on the western continental margin. In the Basin and Range province, to the east, upwelling from the mantle behind the subduction zone was creating a spreading center with crustal extension and normal faulting.

Near the end of Oligocene time, when the Farallon plate had been completely consumed beneath the American plate (Atwater, 1970) a major change in the regional tectonics occurred. The east-west compressive forces gradually ceased and a new north-south compressive stress system began. The Pacific and American plates came into direct contact with each other causing the formation of the right-lateral San Andreas transform fault system. The onset of transform continental/oceanic plate relationships produced a series of near-parallel, major rightslip faults splintering the American plate boundary.

in the form of motion between the plates. This was off-shore and to the west of the present-day study area (Dickinson, 1981) in the form of an easterly rising and westward tilting of the Sierran block.

In Pliocene time, tectonic activity intensified with lateral faulting along much of what is now the present-day San Andreas fault system (Dickinson, 1981), and en echelon folding in the southern Coast Ranges west of the study area (Page, 1981). Southwest of the study area, the Transverse Ranges were marked by uplift, thrusting, and lateral faulting. To the east, the Basin and Range regional east-west extension and normal faulting continued. Although forces were still causing the Sierran block to rise on the east it remained internally stable.

2.2.3 Late Cenozoic Tectonic Model: The internal stability and relatively low stresses within the Sierran block have apparently continued into Pleistocene and Holocene time without major change. It is suggested by Wong and Savage (1983) that today, the Sierra Nevada represents a transition zone between shear deformation along the San Andreas fault system and the extensional tectonics of the Basin and Range province. Conversely, Jones and Dollar (1986) indicate the stress field in the southern Sierra Nevada is more compatible with Basin and Range extensional tectonics. Regardless, both works report that the stress field throughout the crust of the Sierran block is uniform and homogeneous.

3 REGIONAL GEOLOGY

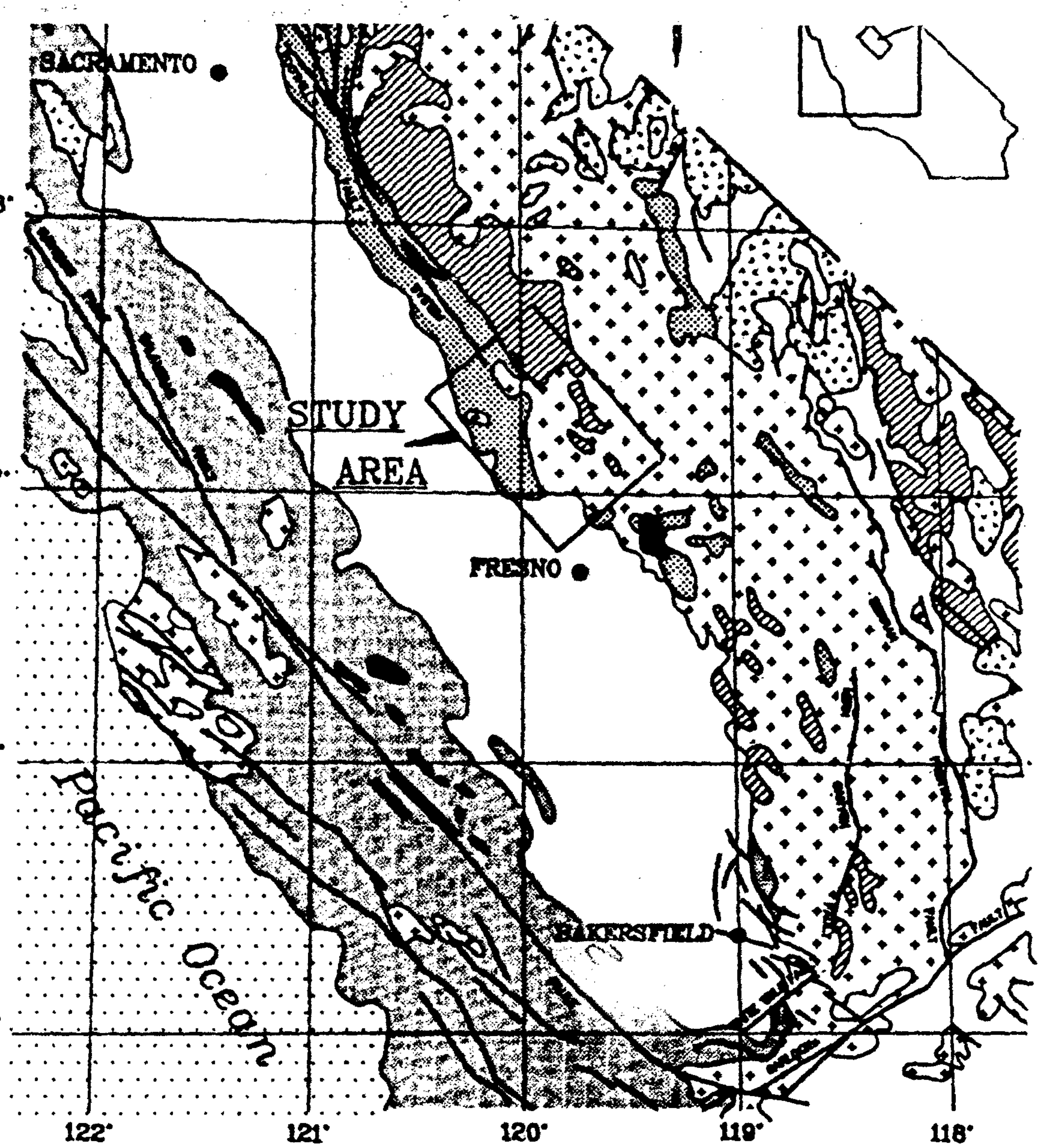
3.1 General. Hidden and Buchanan Dams are located in the western foothills of the Sierra Nevada Range along the eastern boundary of the Great Valley. The study area encompasses about 1,750 square miles (4,533 square km) extending from near Merced in the north, to near Fresno in the south (Figure 1-1 and Plate 1).

The topography of the region, progressing from west to east, is characterized by nearly level to rolling landscape of the San Joaquin Valley, abruptly giving rise to moderately steep northwest-trending foothills with rounded canyons. In turn, these grade to steeper terrain with deeply incised canyons to the east. Elevations within the study area range from 300 feet (91 km) in the valley to approximately 6,000 feet (1,829 km) near the southeastern corner of the study area.

The canyons have been cut by numerous southwestward to westward-flowing rivers and their large tributaries. The largest of these in the study area include the Chowchilla, Fresno, and San Joaquin Rivers. Upon exiting the foothills, these drainages become the principle source of sediments deposited in the eastern San Joaquin Valley during the Quaternary period.

3.2 Geologic Units: The dominate geologic units in the southwestern Sierra Nevada and foothill region consist of Paleozoic and Mesozoic metamorphic and plutonic rock, Cenozoic sedimentary and volcanic rock, and alluvium as shown on the General Geologic Map. Figure 3-1, and on Plate 1.

3.2.1 Pre-Tertiary Metamorphic Rock: The major units present within the Western Metamorphic Belt west of the Melones and Bear Mountains fault zones are of Mesozoic age and include the following:



Alluvial deposits

Cenozoic volcanic rock

Mesozoic–Cenozoic sedimentary rock

Mesozoic metamorphosed sedimentary and volcanic rock, includes Logtown Ridge and Mariposa Formations

Paleozoic metamorphosed sedimentary and volcanic rock, includes Calaveras Formation

Ophiolitic rock

Granitic rock

GENERAL GEOLOGIC MAP

FIGURE 3–1

1. Copper Hill, Gopher ridge, and Penon Blanco Volcanics which consist primarily of diabase and amphibolite that was derived from rocks of basaltic, andesitic, and rhyolitic compositions.

2. Salt Springs Slate which consists primarily of black sericite slate with graywacke and tuff.

3. Mariposa Formation which consists chiefly of black slate and silty shale with tuff and graywacke.

4. Logtown Ridge Formation which consists of metamorphosed mafic breccias, flows, pyroclastic, and volcaniclastic rocks.

The Permo-Carboniferous to Jurassic age Calaveras Complex is the major geologic unit in the Western Metamorphic Belt east of the Melones and Bear Mountains fault zones. Rocks of the Calaveras Complex and their equivalents, which for this report shall all be referred to as the Calaveras Complex, form the eastern boundary of the Melones fault zone, and to the south, the eastern boundary of the Kings River ophiolite and the Kings-Kaweah suture.

The Calaveras Complex consists of metamorphosed siliceous argillite, siltstone, and chert with lesser amounts of limestone, quartzose clastic rock, and volcanic rock (Saleeby, 1975). South of the Merced River area the Calaveras Complex forms most of the numerous roof pendants within the Jurassic-Cretaceous plutonic rock of the Sierra Nevada batholith.

3.2.2 Pre-Tertiary Plutonic Rock: During the Late Jurassic to Cretaceous time, numerous episodes of plutonic emplacement created the Sierra Nevada batholith and further altered the existing rock. The composition of the plutonic rocks ranges from ultramafic intrusives, commonly associated with the major fault zones of the Western Metamorphic Belt, to the more silicic rocks collectively referred to as granitics. These granitics vary from gabbros and diorites to quartz diorite, quartz monzonite, granodiorite, and granite. Late Cretaceous intrusives form the largest body of

plutonic rock in the Sierra Nevada batholith. They consist mainly of quartz diorite and granodiorite. These rocks intruded not only the Paleozoic and Mesozoic rock, but also some of the older Jurassic plutonic rock (Saleeby, 1975).

3.2.3 Tertiary Sedimentary and Volcanic Rock, and Quaternary Alluvium: The Sierran block bedrock complex is unconformably overlain along the western edge of the Sierra Nevada by Tertiary sedimentary rocks of the Ione, Valley Springs, Mehrten, Auberry, and Laguna Formations, and the North Merced Gravel (see Chapter 4 and Appendix A). The deposition of these formations appears to have been in response to tectonism, volcanism, and perhaps climatic events. The Quaternary age Turlock Lake, Riverbank, and Modesto Formations appear to have been deposited in response to Sierra Nevada glaciation due to climatic events only (Marchand and Allwardt, 1978).

3.3 Regional Structure: Structurally, the Sierra Nevada is a large, westward-sloping fault block that has been locally modified by internal faulting. Most of the deformation apparently took place prior to or contemporaneously with the emplacement of the plutons, and the formation of the Foothills fault system. Uplift and faulting during Plio-Pleistocene time produced the present profile of the Sierra Nevada which includes elevations in excess of 14,000 feet (4,267 km) above sea level.

The pre-Cretaceous juxtaposition of subducted oceanic terrane against the existing continental margin produced the northwest-trending Western Metamorphic Belt with its predominant N.18°W. structural trend. These same processes created the Foothills fault system and apparently also resulted in the formation of the Kings-Kaweah suture zone which is comprised of a 78-mile (125 km) long belt of mafic and ultramafic rocks between the Kings and Tule Rivers. Both structures exhibit the same structural trend, contain steeply dipping faults or shear zones, and have rocks with slaty cleavage and a north-to-northwest trending foliation.

A second major structural trend resulted from the emplacement and cooling of the Sierra Nevada batholith. This produced localized curvilinear structural patterns which are most apparent adjacent to, and at the perimeters of, the Cretaceous intrusive plutons. They are often expressed as narrow, linear gneissic zones which are foliated parallel to the contact with the adjacent metamorphic rock. The combination of both the contact metamorphism and the concentric jointing, produced by the cooling of the plutons, resulted in areas of regional curvilinear structure.

A third structural trend is expressed as an apparent conjugate system of northeast-southwest oriented fractures and joints, also within the intrusive plutons.

These three prominent structural trends were detected by the imagery analysis and are expressed as photolineaments on Plate 1.

4 AREAL GEOLOGY

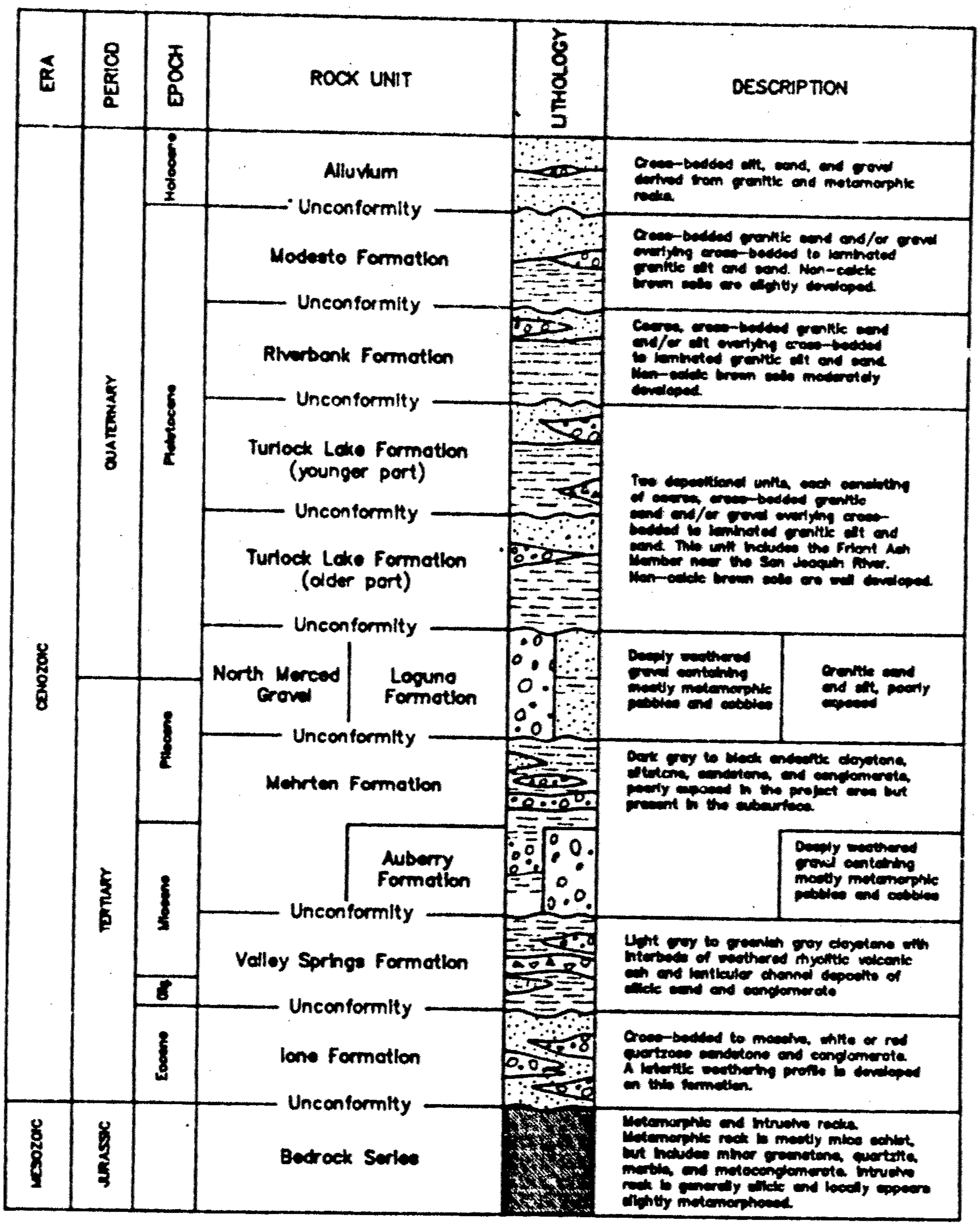
4.1 General. The areal geology is presented as follows: (1) Pre-Tertiary Bedrock Units; (2) Tertiary Units; and (3) Quaternary Units; and is shown on the Generalized Stratigraphic Column, Figure 4-1 and on the Geologic and Lineament Map, Plate 1. Much of the information contained in Sections 4.2 and 4.3 is extracted from Appendix A which, along with Plate 1 was prepared for the Corps of Engineers by Robert H. Wright, PhD, of Harlan Miller Tait Associates. The information contained in Section 4.4 is primarily from Appendix B and was prepared for the Corps of Engineers by Roy J. Shlemon, PhD.

Plate 1 uses a non-drafted grid system desigrated on the plate by sets of "tic" marks associated with either letters or numbers. The capital letters A through I represent non-drafted, north-south parallel lines: the large, bold numbers 1 through 8 represent non-drafted, east-west parallel lines. Feature locations on Plate 1 are then written as a combination of one grid letter and one grid number, often followed by a smaller number depicting a number designating the actual feature shown within the grid. An example is F7-1, the approximate location of a photolineament and of Trench 1.

4.2 Pre-Tertiary Bedrock Units.

4.2.1 Undifferentiated Metamorphic Rocks. "The undifferentiated metamorphic rocks in the study area, compiled on Plate 1 (Mm), consist of Mesozoic sedimentary and volcanic eugeosynclinal rock. These rocks were accreted to the North American plate and metamorphosed as at least two separate terranes, the Merced River and the Foothills terranes, during Middle Jurassic and Late Jurassic respectively, of the Nevadan orogeny (Nokleberg, 1983). Geologic units within the undifferentiated metamorphic rocks unit include the Copper Hill, Gopher Ridge, and Penon Blanco Volcanics, Salt Springs Slate, and Mariposa and Calaveras Formation."

GENERALIZED STRATIGRAPHIC COLUMN



SOURCE:
MODIFIED FROM PG&E, 1977

FIGURE 4-1

4.2.2 Undifferentiated Intrusive Rocks. "The undifferentiated igneous intrusive rocks in the study area, compiled on Plate 1 (Mi) consist of Mesozoic plutonic rocks of the Sierran Nevada batholith intruded into the Mesozoic eugeosynclinal rocks during the Nevadan orogeny. These rocks range in composition from ultramafic intrusives associated with major fault (suture) zones to granitic rocks which vary in lithology from gabbros and diorites to quartz diorite, quartz monzonite, granodiorite and granite..." as described by Bateman and others (1983). Color, texture, and compositional changes are apparently the result of structural deformation and hydrothermal effects associated with later intrusive episodes. Characteristic features within the intrusive rocks often include large hornblende prisms, mafic xenoliths, and localized orientation of prismatic minerals.

4.2.3 Hidden Dam Foundation. The upper portion of the Hidden Dam spillway and left abutment is underlain by a complex mixture of intrusive granitic and associated migmatitic rocks. The migmatite, which is classified as a granite gneiss (USACE Foundation Report, Hidden Dam, 1977), consists of alternating zones of light gray, massive, silicic granitic rock with dark gray and white gneissic rock. The gneiss locally grades into very closely banded dark gray to nearly black schist. In the gneissic and schistose rock types, some of the banding is smooth and parallel and some is undulating, complex or contorted.

Numerous minor shears and faults were encountered during the excavation for the dam. The structures appear to be localized in the riverbed and left abutment and occur in both the granitic and metamorphic rock. There is no known evidence of recent faulting, but rather the structures appear to be related to the regional deformation in the Sierra Nevada and the emplacement of the nearby intrusive bodies.

4.2.4 Buchanan Dam Foundation. The main dam and the downstream portion of the spillway are underlain by metamorphic rocks consisting primarily of fine grained quartz-mica schist. They

exhibit intense shearing and prominent foliation. The rocks are cut by numerous lenticular bodies and veins of milky quartz. Near the contact with the intrusive bodies, the schist contains scattered zones of migmatite. The migmatite, which is classified as a granite gneiss as described above in paragraph 4.2.3.

The degree of jointing is moderate to high in the quartz-mica schist and moderate to slightly fractured in the granitic rock. Jointing in the schist is most prominent along the planes of schistocity. The rock tends to split into tabular plates and generally has a slabby appearance. Joint surfaces in the granitic rock are typically iron oxide stained with some localized clay coating.

4.3 Tertiary Units.

4.3.1 Ione Formation (Eocene). "The oldest Cenozoic deposit in the study area is the middle Eocene age sandstone and kaolinitic clay of the Ione Formation (Ti on Plate 1). The formation, resting unconformably on bedrock, is characterized by white sandy clay near the base and layers of sandstone and quartz-rich conglomerate in the upper part. This material accumulated in a fluvial, deltaic and shoreline marine environment. The formation crops out in a discontinuous band a few miles wide adjacent to the belt of metamorphics along the east side of the Great Valley from Folsom in the north to Fresno in the south. The formation dips about 2 to 4 degrees and thickens to the west, and is progressively covered by younger sediments. The greatest exposure thickness of the Ione Formation is 95 feet (29 m); however, Davis and Hall (1959) estimate it has a maximum thickness of 200 feet (61 m) based on width of outcrop and regional dip."

4.3.2 Valley Springs Formation (Oligocene and Miocene). "The Valley Springs Formation (Tv on Plate 1) is primarily composed of fluvially deposited rhyolite tuffs and tuffaceous sediments of late Oligocene to middle Miocene age (Dalrymple, 1963; Slemmons, 1966). It crops out extensively north and east of Merced. It is

soil types commonly associated with the Valley Springs Formation farther north."

4.3.3 Auberry Formation (Miocene?). "The reddish-stained cobble gravels of the Auberry Formation of Janda (1965; Ta on Plate 1) are exposed around the base of Little Table Mountain, a prominent butte at the head of the San Joaquin River alluvial fan, and in low hills nearby (Janda, 1966), and crop out in a discontinuous band extending to just north of the head of the Fresno River alluvial fan. These contain many locally derived metamorphic pebbles and cobbles. The gravels are differentiated from younger gravels by their dark staining, more advanced state of weathering, and greater induration. The gravels were deposited as early alluvial fan sediments of the San Joaquin River. They are Miocene in age based on a potassium-argon date of 9.5 ±0.3million years obtained from an upper basalt member of the Auberry Formation exposed east of Millerton Lake (Dalrymple, 1963; Berggren, 1972)."

4.3.4 Mehrten Formation (Miocene and Pliocene). "The Mehrten Formation (Tm on Plate 1) ranges in age from late Miocene to early Pliocene (Axelrod, 1957; Slemmons, 1966). The formation is composed of a distinctive sequence of dark sandstone, conglomerate, and claystone. The material is largely andesitic, with less than 50 percent of other rock and mineral fragments. The type section of the Mehrten Formation is 45 miles (72 km) north of Modesto in the northeast part of San Joaquin County (Piper and others, 1939). The Mehrten Formation crops out extensively north and east of Merced, and extends south as isolated patches to the north of Madera."

4.3.5 Laguna Formation (Pliocene and/or Pleistocene). "The Laguna Formation (QTl on Plate 1) consists of an upper cobble gravel (China Hat Gravel member) and a lower member consisting of yellowish weakly- to moderately-indurated arkosic sand, silt, and

discontinuous band extending from just north of the head of the Chowchilla River alluvial fan to north and east of Merced."

4.3.6 North Merced Gravel (Pliocene and/or Pleistocene). "The North Merced Gravel (QTm on Plate 1) consists of locally derived pebbly and cobbly gravel deposited as pediment veneers. It crops out from north of the Merced River to south of the San Joaquin River (Hudson, 1960; Arkley, 1962a, 1962b; Janda 1966; Helley, 1966). These late Pliocene to Pleistocene gravels are unconformable with both younger and older sediments."

4.4 Quaternary Units. "...three general Quaternary geological formations are now well recognized on the east side of the San Joaquin Valley: Modesto (youngest), Riverbank, and Turlock Lake (Davis and Hall, 1959). These formations are best expressed as fluvial-fill terraces flanking major westward-flowing rivers, such as (for the Hidden and Buchanan area) the Merced and the San Joaquin, and to a lesser degree as terrace and alluvial fan sediments associated with the Chowchilla and Fresno rivers and Berenda Slough."

"The Quaternary formations are generally distinguished from each other by their elevations above local stream base level, by degree of topographic dissection, and by relative soil profile development." "...Arkley (1962a)... first pointed out the probable relationship of Sierra Nevada glaciations to the formations (outwash) in eastern Merced County. These concepts were verified by Janda (1965), Janda and Croft (1967), and Shlemon (1967, 1972)...." "...data studies confirmed that the Modesto, Riverbank, and Turlock Lake Formations, and their respective members, can be equated with regional changes of climate and sedimentation during the Quaternary...."

Representative soil-geomorphic relationships are shown in Table 4-1.

…SEDIMENTARY GEOLOGY
(Adapted from Appendix A)

GEOLOGIC FORMATION (Quaternary and Tertiary)	MAPPED SOIL SERIES
Modesto	Delhi, Hanford, Dinuba, Greenfield
Riverbank	San Joaquin, Snelling, Ramona, Madera, Exeter
Turlock Lake	Montpellier, Whitney, Rocklin, Cometa
North Merced/China Hat	Redding, Corning
Laguna	Whitney, Rocklin
Mehrten	Pentz, Peters, Raynor
Valley Springs	Amador
Ione	Hornitos

4.4.1 Formation Ages. Estimated ages for the Turlock Lake, Riverbank, and Modesto Formations were described by Shlemon (1986b) and are as follows:

4.4.1.1 Turlock Lake Formation. "Has at least two major members recognized at the type locality, separated by a very strongly developed buried paleosol (interglacial). Most likely equivalent to several Sierra Nevada glacial events. Age 500,000 to perhaps locally slightly in excess of a million years. Contains the K/Ar-dated 600,000-year-old Friant Ash (Millerton area on the San

Corcoran or "E" clay in the central and western San Joaquin Valley. The Turlock Lake has at least two buried soils in the Sacramento area, the lower of which is immediately above the 730,000-year-old Brunhes/Matuyama paleomagnetic reversal. In Tulare County, the Turlock Lake Formation seems to be dissected, but even significantly eroded slopes still bear moderate to strongly developed soils."

4.4.1.2 Riverbank Formation. "Has at least three members identified in the subsurface by gravel-filled channels, or on the surface by fluvial terraces along major westward-flowing streams. Estimated age is 125,000 to 400,000 or 500,000 years. Probably equivalent to isotope stages 6, 8, and 10, perhaps even older. The period 80,000 to about 125,000 years before the present is approximately the Sangamon interglacial and a time of major soil development on Riverbank-age sediments."

4.4.1.3 Modesto Formation, Lower (older). "Approximately 50,000 to 70,000 years old, but sediments were also locally being deposited during "mid-Wisconsin" 30,000 to 50,000 years ago. Approximately correlative to isotope stage 4 or Tahoe glaciation (early Wisconsin)."

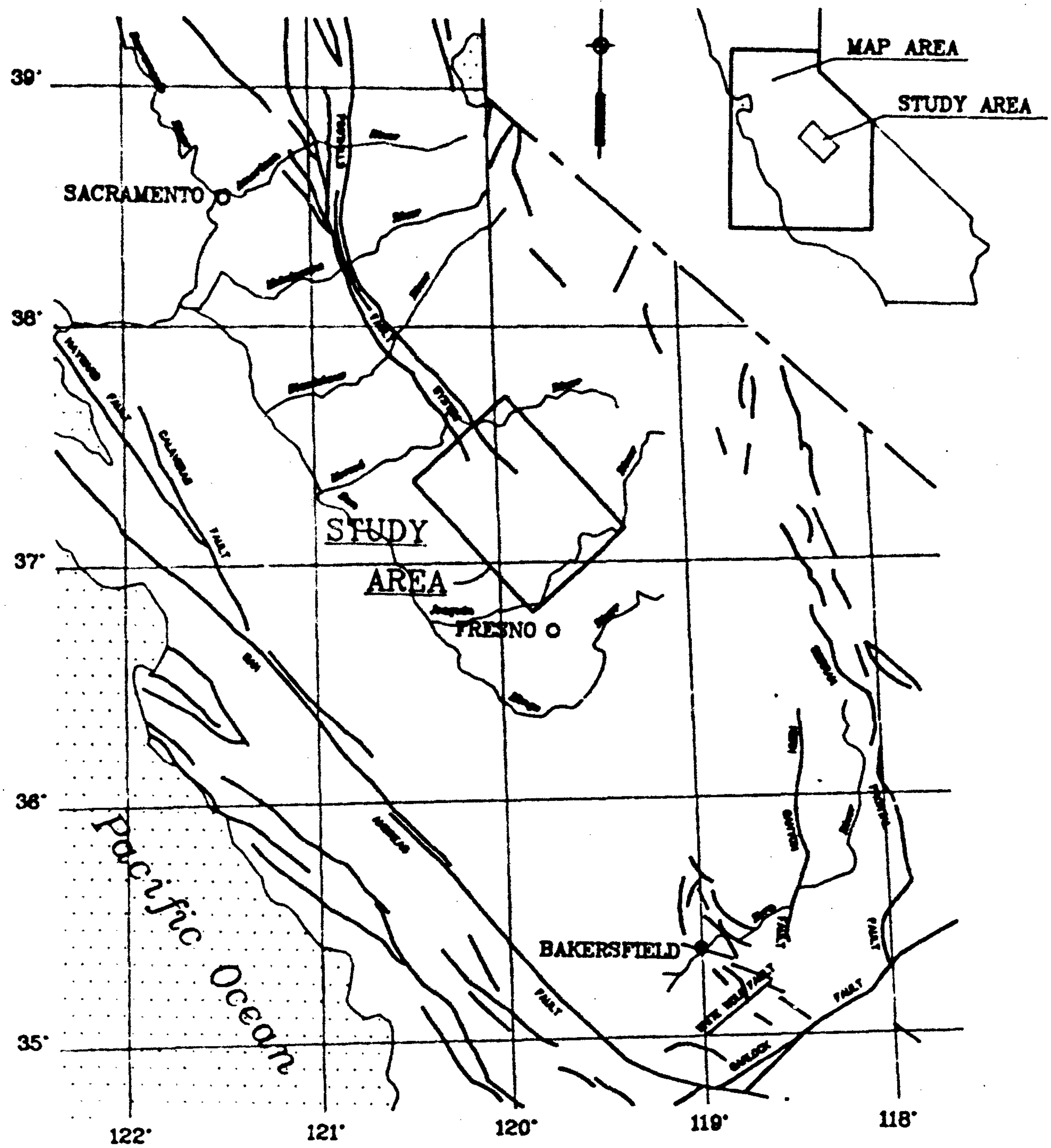
4.4.1.4 Modesto Formation, Upper (younger). "Approximately 10,000 to 30,000 years old, and essentially equivalent to marine isotope stage 2, or to the Tioga glaciation in the Sierra Nevada (late Wisconsin in Midwestern terms)."

5.1 General. The Hidden and Buchanan Dams study area lies within the Sierran structural block. This area is considered tectonically stable and has reacted little to the strong stresses ongoing throughout most of the Cenozoic Era. It has also had little volcanic activity since middle Cenozoic time, in contrast with the Coast Ranges, the Cascade Range, and the desert regions of Southern California.

Present-day seismicity is expressed along two major active fault systems that lie within 70 miles (112 km) of the project area. They are the San Andreas fault system and the Sierran Frontal (Owens Valley) fault system. These faults were recognized during all phases of planning and construction of Hidden and Buchanan Dams. In addition to these two active fault systems, the dams are located near the Melones and Bear Mountains fault zones of the Foothills fault system, and other smaller faults within or adjacent to the study area (See Regional Fault Map, Figure 5-1, and Geologic and Lineament Map, Plate 1).

5.1.1 San Andreas Fault System. The San Andreas fault system is considered to be one of the most likely sources of seismic events which could significantly affect Hidden and Buchanan Dams. This is a system of primarily right-lateral strike-slip faults which form a continuous zone approximately 680 miles (1,094 km) in length along the California continental margin. The San Andreas fault system is considered to be one of the more simple transform faults found in plate tectonic processes (Allen, 1981).

The San Andreas fault system is not represented by one continuous rupture, but instead it is a zone of fractures which often have en echelon or anastomosing traces that are given individual fault names. As an example, the Richter magnitude (M) 6.2 Coalinga earthquake of May 2, 1983 probably occurred on a sub-parallel fault to the San Andreas fault system. The name "San Andreas



REGIONAL FAULT MAP

NOT TO SCALE

FIGURE 5-1

fault" is assigned to the alignment of the most prominent faults of this system.

5.1.2 Sierran Frontal (Owens Valley) Fault System. The Sierran Frontal (Owens Valley) fault system consists of generally east-dipping normal faults which have a total length of more than 300 miles (483 km). The fault group or system, which is considered to be in the northwest-southeast to east-west extensional tectonic regime of the present Basin and Range Province (Jones and Dollar, 1986), ruptured along a 62-mile (100 km) length in Owens Valley in 1872. That movement generated an earthquake of an estimated M 8+ on a right-lateral oblique normal-slip fault (Oakeshott et al, 1972). Recent activity on this system has been occurring (see Chapter 7, Seismology), and therefore, this system is comparable to the San Andreas fault system for seismic activity and hazard potential to Hidden and Buchanan Dams.

5.1.3 Foothills Fault System. The Foothills fault system, which is principally comprised of the Melones and Bear Mountains fault zones, is considered to represent the suturing of Mesozoic accretionary terrane to the more easterly Paleozoic basement terrane. The fault system extends several hundred miles from the northern Sierra Nevada foothills southward to the Merced River area. Although the Foothills fault system, as mapped, ends in the Merced River area, numerous investigators (Saleeby, 1975; Schweikert and others, 1977; Bateman and others, 1983; and Nokleberg, 1983) have identified shear zones in metamorphic rock south of the study area (Kings-Kaweah suture), which they consider to be a southern continuation of the fault system. The entire fault system had generally been considered non-capable, until the August 1, 1975 M 5.7 Oroville earthquake. This event was located approximately 186 miles (298 km) northwest of the study area and although it did not occur directly on the Foothills fault system, it is thought to have occurred on an associated fault. Within the study area of this report, a M 4.2 to 4.9 epicenter was reported approximately 11 miles (18 km) east of Buchanan Dam on August 9, 1975 (USDOC, 1975), just 7 days

after the Oroville event. However, neither this investigation nor Harlan Miller Tait (Appendix A, pages 29-31) found any direct evidence of capability for faults in the Melones or Bear Mountains fault zones within the study area.

5.1.3.1 Melones Fault Zone. The southern portion of the Melones fault zone is designated as D2-1 on Plate 1. The Melones fault zone marks the easternmost structure in the northwest-trending Foothills fault system. The southern portion of the fault zone separates rocks of the Paleozoic age Calaveras Formation on the east, from the Mesozoic age Mariposa slate on the west. The fault zone, as mapped, extends approximately 15 miles (24 km) into the northern end of the study area, and appears to be truncated just southeast of Mariposa by Mesozoic igneous rocks of the Sierra Nevada batholith. Although the direction and amount of displacement on the fault zone are not well understood, Duffield and Sharp (1975) suggest vertical displacement on the order of hundreds or possibly thousands of meters, with no indication of lateral movement.

5.1.3.2 Bear Mountains Fault Zone. The southern portion of the Bear Mountains fault zone, as shown on the Fault Map of California (1975), is designated as C2-1 on Plate 1. Paterson and others (1987) suggest that the fault continues south into the study area on the west side of the Guadalupe igneous complex (D3 Plate 1) as a large ductile shear zone. They consider this fault zone to be steeply dipping to the east with a small left-lateral component. Although the inferred continuation corresponds to lineament C3-2 and could possibly be assumed to continue as far south as lineament E5-6 on Plate 1, the zone appears to be breached by a small Mesozoic igneous pluton northeast of Mariposa Creek Dam (D4), and thus the southern portion of the Bear Mountains fault zone is considered to be non-capable (Appendix A, page 31).

5.2 Faults: Existing, Postulated or Inferred, Within the Study Area. The Following is a summary of information contained in Appendix A.

5.2.1 Existing Faults.

1. St. Mary's Mine Fault - Lineament. The fault is designated as C3-1 and the lineament as C3-2 on Plate 1. These structures were investigated by Pacific Gas and Electric Company (PG&E, 1977) for the proposed Merced nuclear power plant. There are no known Cenozoic deposits overlying the fault. However, it is considered to be of Mesozoic age and non-capable (HMT, 1987).

2. Hidden Dam Foundation Fault. During construction of the dam several bedrock faults, cutting Mesozoic intrusive rock (quartz diorite), were exposed in the foundation explorations (USACE, 1977). These were primarily in the riverbed and the imperious core foundation adjacent to the east side of the outlet works. The excavation exposed many irregular fault planes (footwall surfaces) that were moderately weathered. Deeper excavation and cleanup along the faults exposed the hanging wall with sheared and brecciated rock varying from about 0.2 to 4.5 feet (0.06 to 1.4 meters) thick and containing gouge, chlorite, slickensides, bluish gray to grayish green altered rock, quartz and calcite fracture fillings, and scattered sulfides. The southeast end of the longest fault found (460 plus feet long, (140 meters)) terminated in the highly weathered granitic foundation rock without further trace. No evidence of recent fault activity could be determined. These faults are considered to be related to regional deformation in the Sierra Nevada and the emplacement of nearby intrusive rocks, and are therefore not capable of producing future earthquakes.

5.2.2 Postulated or Inferred Faults.

1. Raymond to Auberry Bedrock "Faults". Features designated as E5-1 and 2, and H5-1 through 6 on Plate 1 were investigated by PG&E (1977) for the proposed Merced

nuclear power plant. No evidence of faulting was proven. One of the features is partly overlain by undisturbed Miocene Auberry Formation basalt, which is approximately 9-million years old (Dalrymple, 1963; Bergren, 1972).

2. County Line Lineament - Postulated Fault. This feature is designated as C4-1 on Plate 1. A portion of this northwest-southeast trending lineament has been postulated to be of fault origin. However, much of it coincides with a mid-1800's road which was constructed along the present County line (HMT, 1987), suggesting a possible cultural origin. This feature, as investigated by this study, see paragraph 6.2.6, was determined not to be a fault.

3. Page and LeBlanc Lineament - Postulated Fault / Clovis Inferred Fault. This feature is designated as G7-1 on Plate 1. This postulated fault and/or associated lineament is shown as a dotted (concealed by younger rocks) pre-Quaternary fault on the Fault Map of California (1975). Fugro Inc. (1974) investigated this lineament and found no evidence of bedrock offset and found undisturbed Eocene Ione Formation overlying the trace. Therefore, this feature is not considered to be a capable fault.

4. "Berenda Slough Inferred Fault". This feature is designated as D6-1 on Plate 1. It was inferred by Marchand and Allwardt (1978) and was investigated for this report, see paragraph 6.2.4. No evidence of a fault was found.

5. "Avenue 15 Inferred Fault". This feature is designated as E7-1 on Plate 1. It was inferred by Marchand (1976b) from an apparent offset in Turlock Lake Formation sediments and was investigated by this report, see paragraph 6.2.2. No evidence of a fault was found.

6. Millerton Lake Lineament - Postulated Fault. This feature is designated as G7-2 on Plate 1. It was postulated by Marchand and Allwardt (1978) and was thought to offset the Miocene age Auberry Formation basalt. It was field checked and found not to be a fault (HMT, 1987).

5.3 Faults: Existing, Postulated or Inferred, Adjacent to the Study Area. (See Appendix A for additional information). These features are outside of the study area and are not shown on any figures or plates in this report.

1. Arkley's Postulated Fault Zone. This is a postulated zone, possibly associated with lineaments, located north of Merced and northwest of the study area, near Turlock Lake. This area was studied by PG&E in 1977 for the proposed Madera nuclear power plant and no faults were found.

2. Stoney Creek Fault. This fault is located on the north bank of Stoney Creek, in the SE1/4, NE1/4, Section 17, T5S, R15E, Merced Falls 7.5' Quadrangle. It was studied by PG&E (1977) for the proposed Merced nuclear power plant. The fault is overlain by undisturbed Riverbank Formation and therefore is not considered to be capable.

3. Merced Falls Faults. These faults were located during foundation excavations for McSwain Dam in Sections 3, 10, and 11, T5S, R15E, Merced Falls 7.5' Quadrangle. They displace the Mesozoic age Gopher Ridge Formation, but 1/2-mile northwest along the trends of these faults the Eocene Ione Formation and the Merced Gravels are undisturbed. They were studied by Woodward-Clyde Consultants (1975), and are not considered to be capable.

4. Merced River Gorge Faults (2). These faults are located in Section 35, T4S, R15E, Merced Falls 7.5' Quadrangle.

The faults were studied by Woodward-Clyde Consultants (1975) and are not considered to be capable.

5. Big Bend Fault. This fault is located in the SW1/4, Section 15, T4S, R14E, of the Snelling 7.5' Quadrangle. It was studied by PG&E (1977) for the proposed Merced nuclear power plant. It is overlain by undisturbed North Merced Gravels, possibly Turlock Lake Formation, and is not considered to be capable.

6. Hayward Creek Fault. This fault is located in Sections 32, 33, 34, 35 and 36, T3S, R14E, La Grange and Snelling 7.5' Quadrangles and was studied by PG&E (1977). It is overlain by undisturbed Ione Formation and is not considered to be capable.

7. Gill Ranch Gas Field Faults. These faults are located southwest of the study area. Quaternary offsets have not been found and therefore, these faults are not considered to be capable.

8. China Hat Fault - Lineament. This northwest-trending lineament, associated with the China Hat fault, was located 6 to 9 miles (10 to 14 km) north-northwest of Merced in the area studied by Marchand and Allwardt (1978). No evidence of late Quaternary displacement was found and it is not considered to be capable.

9. Canal Creek Lineament - Inferred Fault. This northwest-trending lineament is located 6 to 11 miles (10 to 18 km) north-northwest of Merced and this study area, parallel to and 1.5 miles (2.4 km) west of the China Hat lineament. This fault was inferred by Marchand and Allwardt (1978) to possibly truncate the Laguna Formation but no fault or displacement has ever been proven, therefore, it is not considered to be capable.

6.1 General. As previously stated in Chapter 1, one component in the 1977 Corps of Engineers Dams Safety Assurance Program is to review the seismic loading design for Corps projects. The first step in the review process was reconnaissance level geologic studies and reports. In May 1985, the Sacramento District had completed two reports entitled: "Geologic Reconnaissance of the Hidden Dam and Hensley Lake Area, Madera County, California"; and "Geologic Reconnaissance of the Buchanan Dam and Eastman Lake, Madera County, California."

The reconnaissance reports discussed known and inferred faults and posed questions concerning the presence, extent, and capability of faults within the study area. To answer these questions required detailed mapping and definitive age determinations for all the known, postulated, and/or inferred faults in the area. This information was not available. Therefore, the Sacramento District (1) developed a detailed and specific scope of work for a photogeologic interpretation and imagery analysis of the Hidden and Buchanan Dams vicinity, (2) advertised a request for proposal contract for the imagery analysis, and (3) awarded the contract to the firm of Harlan Miller Tait Associates (HMT), San Francisco, California on May 8, 1987.

Harlan Miller Tait's report, dated September 1987, elaborated on the Corps' 1985 reconnaissance reports and recommended that the Corps investigate by trenching and detailed logging, several of the suspected faults and lineaments located during both the Corps' and HMT's literature searches, and also investigate several lineaments determined by HMT's field study to merit further attention. On September 8, 1987, with contracted backhoe services, Corps of Engineer's geologists began excavating six recommended trench sites and logging the Quaternary sediments and soils (pedogenic profiles). Roy J. Shlemon, PhD field reviewed the trench logging and made age determinations using soil-

... trenches were backfilled in December 1987.

6.1.1 Lineament Trends. Common to the southeastern edge of the San Joaquin Valley are a series of aligned swales and gullies having generalized trends of N.20°W. to N.50°W. These landforms and trends roughly parallel the foothill margins, but become obscured by the younger alluvial deposits to the west toward the valley center. Marchand and Allwardt (1978) noted that the strike of the Tertiary Ione, Valley Springs, Mehrten, and Laguna Formations also varies from N.20°W. to N.50°W. These structural attitudes apparently had some controlling influence during the development of the dissected terrain seen on most of todays exposed Tertiary surfaces and which are reflected in the overlying early Quaternary formations.

The N.20°W. to N.50°W. trend is also that of major photolineament sets detected in imagery analyses by lineament studies accomplished in this area, including those by: PG&E for proposed nuclear power plants (1977); by the USGS, Marchand and Allwardt (1978) and Hodges (1979); and by this investigation.

6.1.2 Deformation and Deposition of Tertiary and Quaternary Formations. Deformation and deposition of the Tertiary formations are described by Marchand and Allwardt (1981) as:

> "The Ione, Valley Springs, Mehrten and Laguna Formations... deformation appears to have been closely related to tectonic events in the Sierra Nevada; their deposition may have been in response to tectonism, volcanism, and perhaps climatic events as well (Marchand, 1977)."

The Quaternary formations are described by them as follows:

> "The members of the Quaternary alluvial sequence (Turlock Lake, Riverbank, and Modesto Formations, are relatively undeformed... and appear to have been deposited in response to climatic rather than tectonic events."

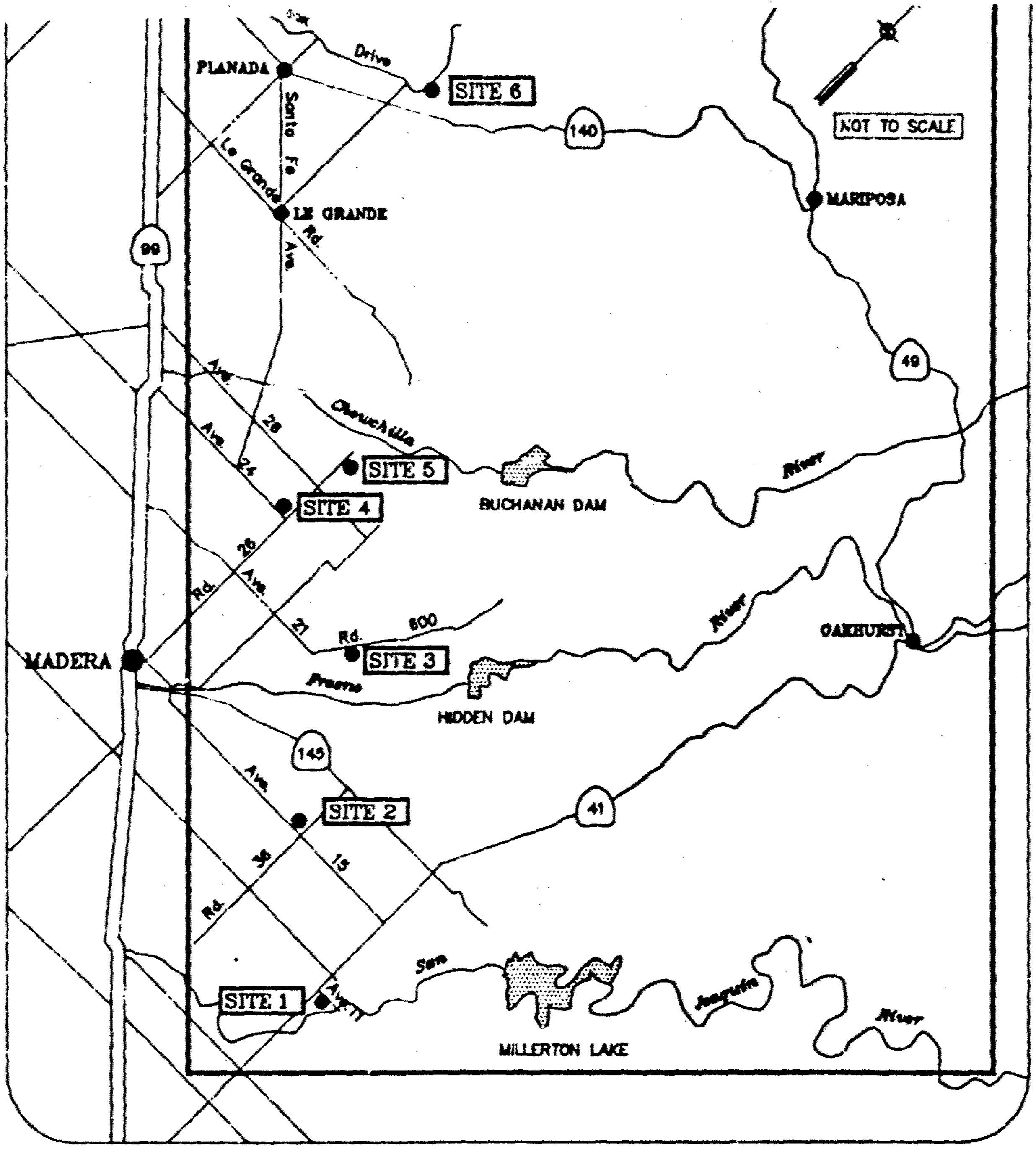
6.1.3 Requirement for Investigation of Selected Lineaments and Inferred Faults Within the Study Area. Although Marchand and Allwardt (1978) do not associate tectonic deformation with the Quaternary formations within the study area, the lineaments do have extensive surface expression. Marchand (1976a through f) and Marchand and Allwardt (1978 and 1981) also seemingly contradict the lack of tectonic evidence for deformation by mapping inferred Quaternary faults within the dissected terrain of the study area. If the lineaments represent Quaternary faults as inferred, then their capability must be assessed to determine what impact they would have on Hidden and Buchanan Dams. Therefore, the Corps undertook the program of investigations described below.

6.2 Trench Investigations. See Figure 6-1 for a generalized map showing all six trench locations. The trench sites are also approximately located on the Geologic and Lineament Map (Plate 1).

6.2.1 Trench 1. See Figure 6-2 for a detailed site location map and Sheets 1, 2, and 3 for logs of Trench 1.

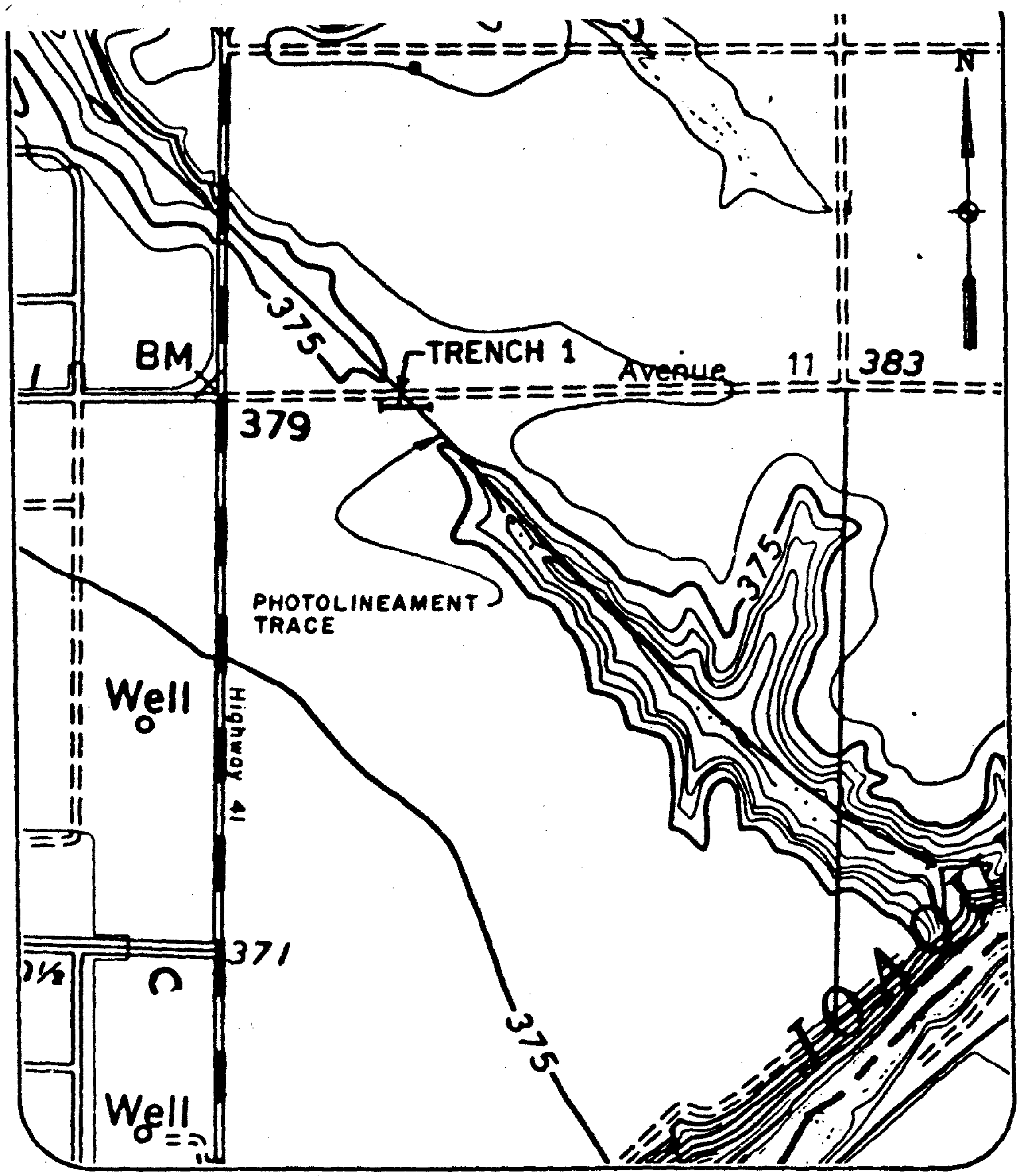
1. Location. Trench 1 was north of the City of Fresno, California, in Madera County southeast of the junction of Highway 41 and Avenue 11 (NW1/4, NW1/4, Section 10, T.12S., R.20E., Lanes Bridge Quadrangle). It was located across a photolineament at approximately F7-1 on Plate 1. This photolineament is the most prominent of a group of northwest-trending photolineaments that Marchand mapped on the north side of the San Joaquin River (1976b). The trench was positioned to cross that lineament at a topographic high in order to encounter the thickest possible sequence of pedogenic profiles.

2. Dimensions. The trench was approximately 240 feet (73 m) long and averaged 8 to 10 feet (2.4 to 3 m) deep.



TRENCH SITE LOCATION MAP

FIGURE 6–1



0 670 1340 Feet

APPROXIMATE SCALE

SOURCE: LANES BRIDGE 7.5' QUADRANGLE
USGS TOPOGRAPHIC MAP

TRENCH 1 LOCATION MAP

FIGURE 6-2

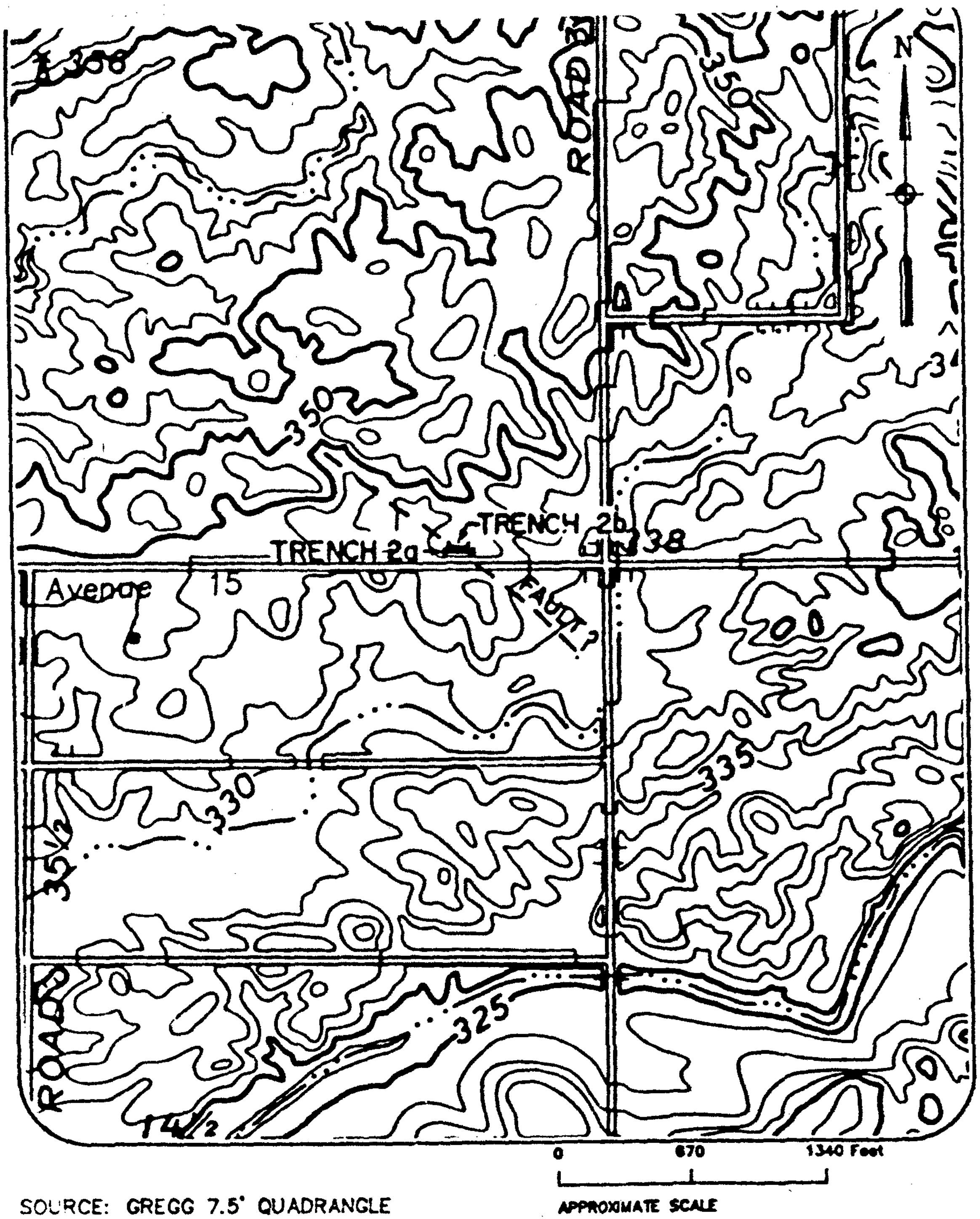
3. Findings. The swale incises the Riverbank Formation as shown by Marchand and Allwardt (1978). The Riverbank sediments in the trench are not faulted, and in the central portions of the swale they are unconformably overlain by Modesto age sediments (Shlemon, Appendix B). An earlier trench had been excavated adjacent to Trench 1, and extended to a depth of 16 feet (4.9 m), but, due to caving conditions it could not be logged. In the lower portions of that trench, the authors believe that undisturbed Turlock Lake age sediments were observed. An ash layer was encountered at the depth of 16 feet that appeared to correlate with a unit identified as Friant Ash in the river bluffs about 0.6-mile (1 km) to the southwest.

The origin of the swale/lineament appears to be fluvial and not tectonic. Based on the presence of undisturbed Riverbank age sediments, no fault activity has occurred in at least the last 125,000 years (Appendix B).

6.2.2 Trenches 2a and 2b. See Figure 6-3 for a detailed site location map and Sheets 4 and 5 for logs of Trench 2a and 2b.

1. Location. Trenches 2a and 2b were located east of the town of Madera, California, in Madera County northwest of the intersection of Avenue 15 and Road 36 (SE1/4, SE1/4, Section 16, T.11S., R.19E., Gregg 7.5' Quadrangle). These trenches, approximately located at E7-1 on Plate 1, were excavated on the top of a low hill, and across a possible fault inferred by Marchand (1976b) from sedimentary structural relationships seen on an adjacent roadcut exposure in Turlock Lake sediments. .

2. Dimensions. Trench 2a was approximately 180 feet (55 m) long and averaged 7 to 10 feet (2.1 to 3 m) deep. Trench 2b was approximately 104 feet (31.7 m) long (only Stations 0+60 through 1+04 were logged) and averaged 8 feet (2.4 m) deep.



SOURCE: GREGG 7.5' QUADRANGLE
USGS TOPOGRAPHIC MAP

TRENCHES 2a and 2b LOCATION MAP

FIGURE 6-3

3. Findings. The Turlock Lake age sediments in the roadcut show a vertical discontinuity in what appears to be horizontal bedding. Without the benefit of subsurface investigations, Marchand must have inferred this to be the result of faulting. However, the trench excavations for 2a and 2b exposed an ancient steepwalled channel which, through stream erosion, had created the discontinuity. Below the steepwalled channel lies undisturbed cross-bedded sand and silt of Turlock Lake age (Shlemon, Appendix B).

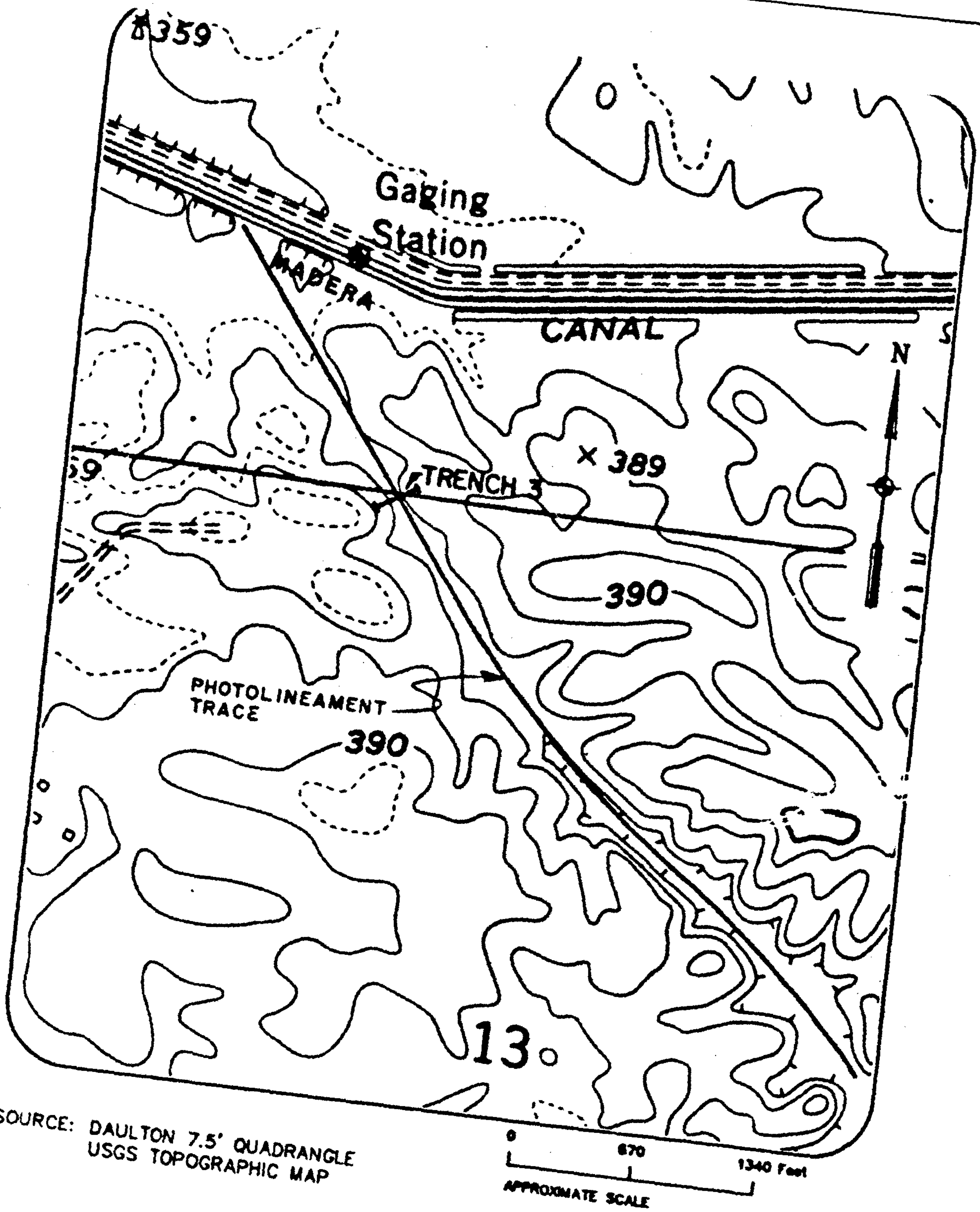
6.2.3 Trench 3. See Figure 6-4 for a detailed site location map and Sheets 6, 7, and 8 for logs of Trench 3.

1. Location. Trench 3 was northeast of Madera, California, in Madera County southeast of Road 600 and about 1,100 feet (335 m) south of the Madera Canal (NW1/4 of Section 13, T.10S., R.18E., Daulton 7.5' Quadrangle). It was located across a prominent northwest-trending lineament originally mapped by Marchand (1976e) at approximately E6-1 on Plate 1. The trench was positioned to cross the swale perpendicular to the photolineament and at a topographic high in order to encounter the thickest possible sequence of pedogenic profiles.

2. Dimensions. Trench 3 was approximately 250 feet (76 m) long and averaged 8 to 10 feet (2.4 to 3 m) deep.

3. Findings. The trench exposed a surfical colluvial deposit of probable Modesto age overlying a strongly developed paleosol which Shlemon (Appendix B) estimates to be a minimum of 100,000 years old. Underlying these units are undisturbed Turlock Lake sediments.

From all available evidence, the origin of the swale/lineament appears to be fluvial and not tectonic.



SOURCE: DAULTON 7.5' QUADRANGLE
USGS TOPOGRAPHIC MAP

TRENCH 3 LOCATION MAP

FIGURE 6-4

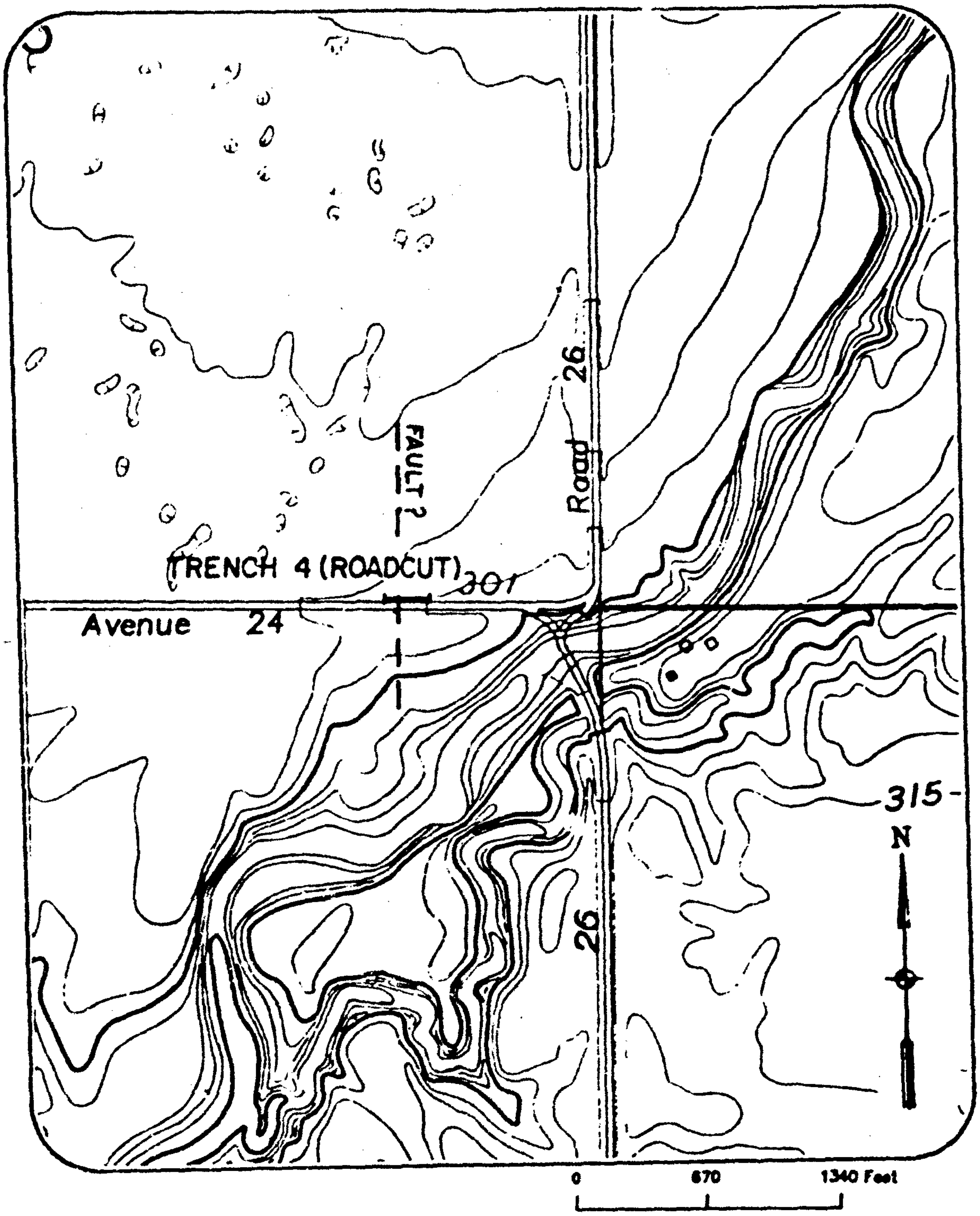
The lack of disturbance of any of the paleosols indicated that no fault activity has occurred in at least 100,000 years.

6.2.4 Roadcut (Site 4). See Figure 6-5 for a detailed site location map and Sheets 9, 10, and 11 for logs of the roadcut (Site 4).

1. Location. This site is north of the town of Madera, California, in Madera County. The site is on a topographic high adjacent to Berenda Creek along the north side of Avenue 24, and approximately 1,000 feet (305 m) west of the intersection with Road 26 (SE1/4, Section 35, T.10S., R.17E., Kismet 7.5' Quadrangle; Marchand and Allwardt, 1978). The queried short, north-trending fault (D6-1 on Plate 1) may have been inferred by Marchand and Allwardt from features observed in the roadcut along Avenue 24. This is the only location where the inferred fault could cross an exposed pedogenic profile. No evidence of any type of offset was detected in exposures to the south along Berenda Creek and no lineaments, topographic expression, or surface anomalies were seen in 1972 photo coverage (prior to the planting of the present-day orchards) viewed at the USDA Soil Conservation Service office in Madera.

2. Dimensions. Approximately 276 feet (84 m) of the roadcut was cleaned of debris by backhoe, exposing 10 to 12 feet (3 to 3.7 m) of cut-slope measured along slope distance.

3. Findings. Two well-defined stratigraphic sequences were exposed, an upper sequence with a strongly developed iron-silica duripan, indicating a probable Riverbank age, overlying a second strongly-developed paleosol of probably early Riverbank age, or more likely according to Shlemon (Appendix B), Turlock Lake age.



SOURCE: KISMET 7.5' QUADRANGLE
USGS TOPOGRAPHIC MAP

ROADCUT (SITE 4) LOCATION MAP

FIGURE 6-5

Both sequences were unfaulted. Although it is unclear what Marchand and Allwardt used to infer a fault at this location, there are numerous carbonate filled vertical cracks which, when observed in a weathered exposure, might appear to be fault related. Data obtained from the cleaned slopes demonstrated that these cracks do not offset lower units and they are truncated by overlying paleosols. Similar cracks were observed in Trenches 1, 2, and 3 and may be what is referred to as joints by PG&E (1977) in their lineament trenching.

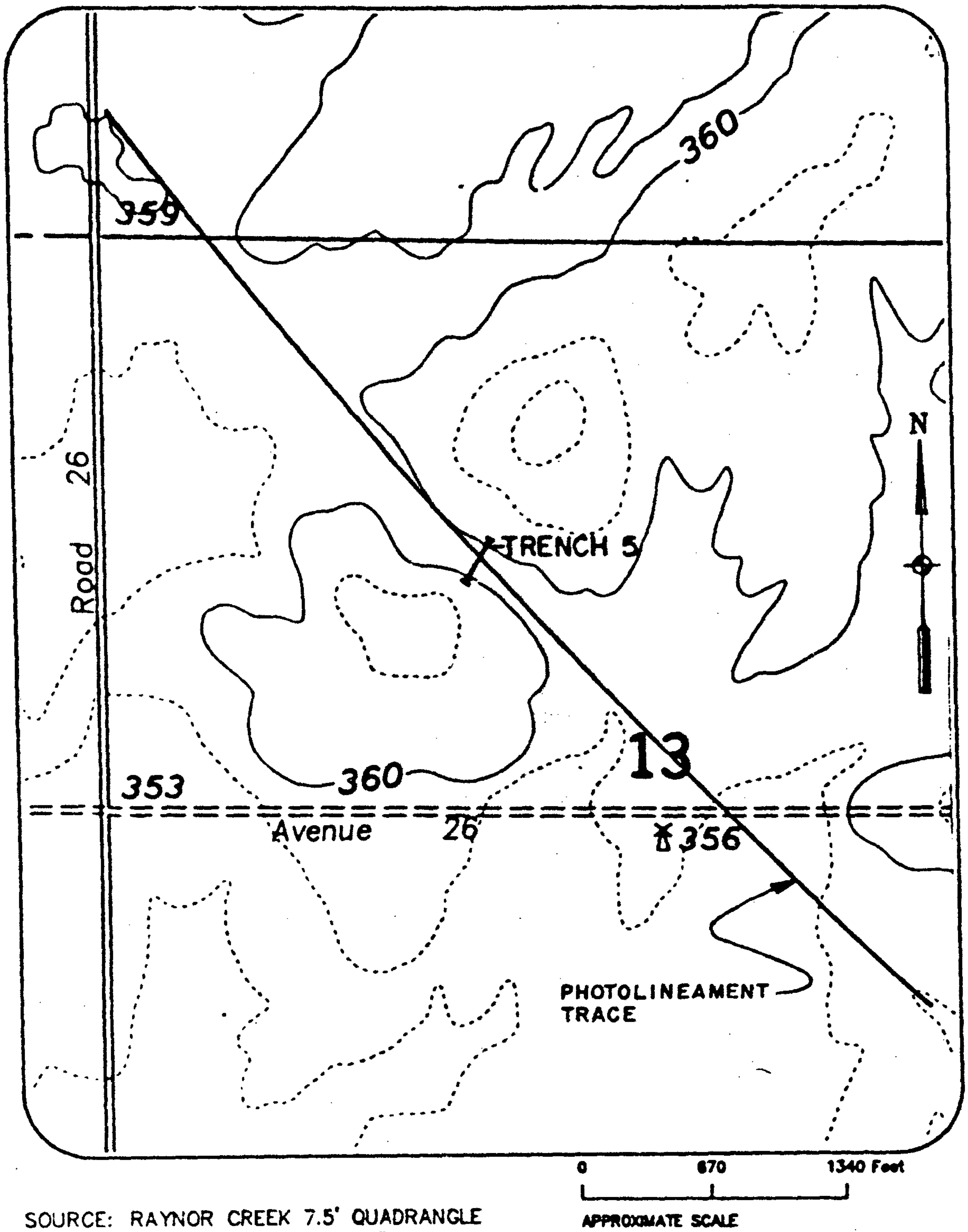
At this location there is no observable evidence of a fault, no photolineament associated with the inferred fault location, no geomorphic expression of faulting, and no disturbance of Turlock Lake sediments at least 400,000 years old.

6.2.5 Trench 5. See Figure 6-6 for a detailed site location map and Sheets 12, 13, and 14 for logs of Trench 5.

1. Location. Trench 5 was north of the town of Madera, California, in Madera County east of Road 26 and north of Avenue 26 (NW1/4, Section 13, T.9S., R.17E., Raynor Creek 7.5' Quadrangle). The trench, at approximately D5-1 on Plate 1, was excavated perpendicular to a major northwest-trending swale which appeared as a photolineament. It was positioned in a topographic high in order to encounter the thickest possible sequence of pedogenic profiles.

2. Dimensions. Trench 5 was approximately 240 feet (73 m) long and averaged 5 to 6 feet (1.5 to 1.8 m) deep.

3. Findings. The trench exposed a surfical colluvial deposit overlying an undisturbed horizontal paleosol of probable Turlock Lake age (Shlemon, Appendix B).



SOURCE: RAYNOR CREEK 7.5' QUADRANGLE
USGS TOPOGRAPHIC MAP

TRENCH 5 LOCATION MAP

FIGURE 6–6

The origin of the swale/lineament appears to be fluvial and not tectonic. At this location there is no geomorphic expression of faulting and no disturbance of the Turlock Lake paleosols at least 400,000 years old.

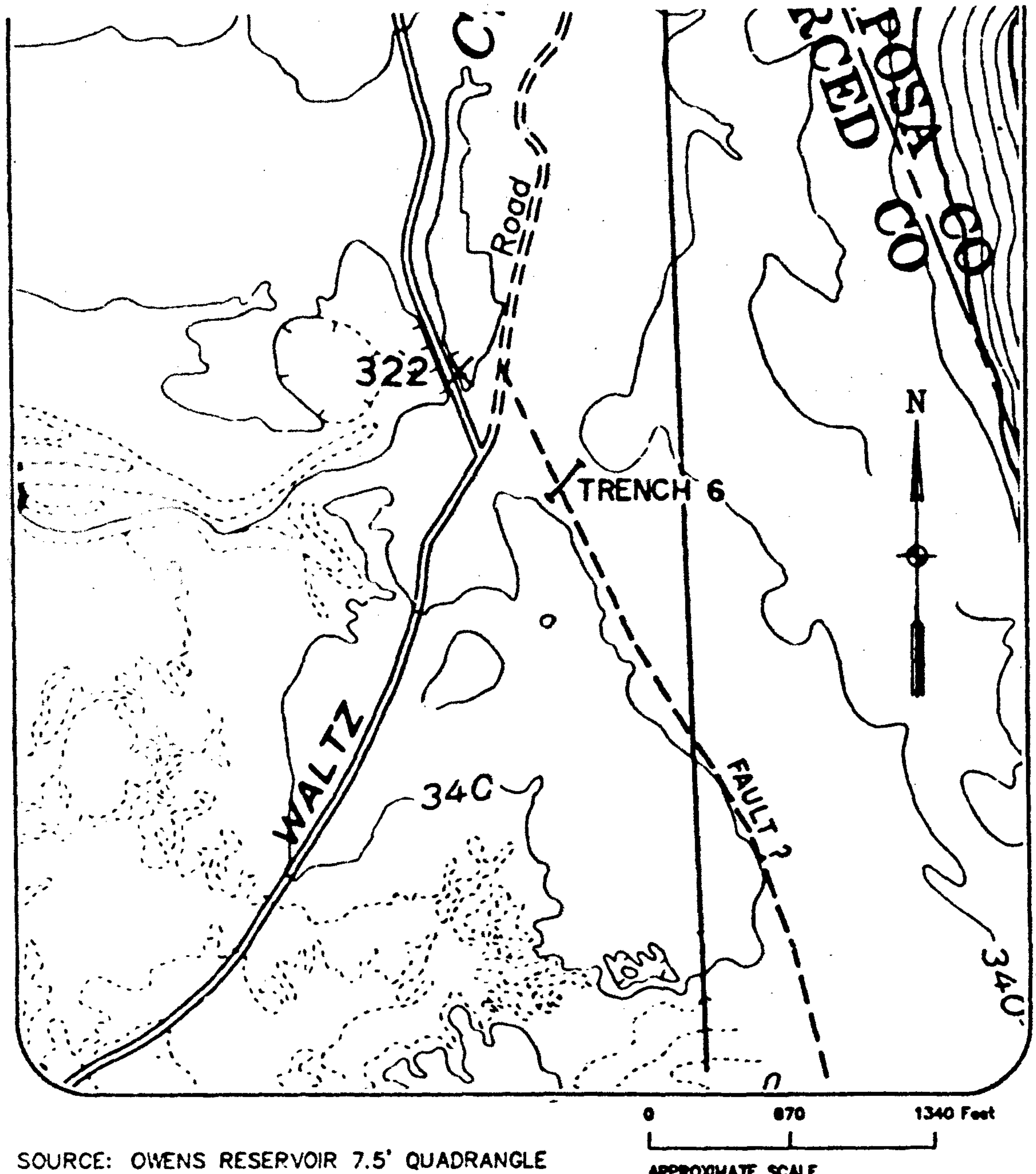
6.2.6 Trench 6. See Figure 6-7 for a detailed site location map and Sheets 15 and 16 for logs of Trench 6.

1. Location. Trench 6 was southeast of the City of Merced, California, in Merced County north of Highway 140 and east of Waltz Road (E1/2, Section 5, T.7S., R.16E., Owens Reservoir 7.5' Quadrangle). The trench crossed the "County Line Lineament" and an inferred fault as defined by Marchand (1976a) and Marchand and Allwardt (1978) at approximately C4-1 on Plate 1. The trench was excavated across a swale, perpendicular to the major northwest-trending photolineament and inferred fault. This trench was positioned along a topographic high in order to encounter the thickest possible sequence of pedogenic profiles. Other possible trench locations were considered during field reconnaissance, but none had the alluvial thickness and topographic advantage of this site and also crossed the inferred fault.

2. Dimensions. Trench 6 was approximately 180 feet (55 m) long and averaged 12 feet (3.7 m) deep.

3. Findings. The trench exposed an upper unit of thick, mostly colluvial clay overlying highly foliated schist, felsic intrusive rocks, and, between Station 0+24 and 0+36, fluvial sand and gravel. No faults were observed in the bedrock.

The colluvium cannot be assigned to one of the regional Quaternary formations, but does contain diffuse carbonate zones, that Shlemon (Appendix B) indicated may date some of the lower materials as much as tens of thousands of years old.



SOURCE: OWENS RESERVOIR 7.5' QUADRANGLE
USGS TOPOGRAPHIC MAP

TRENCH 6 LOCATION MAP

FIGURE 6-7

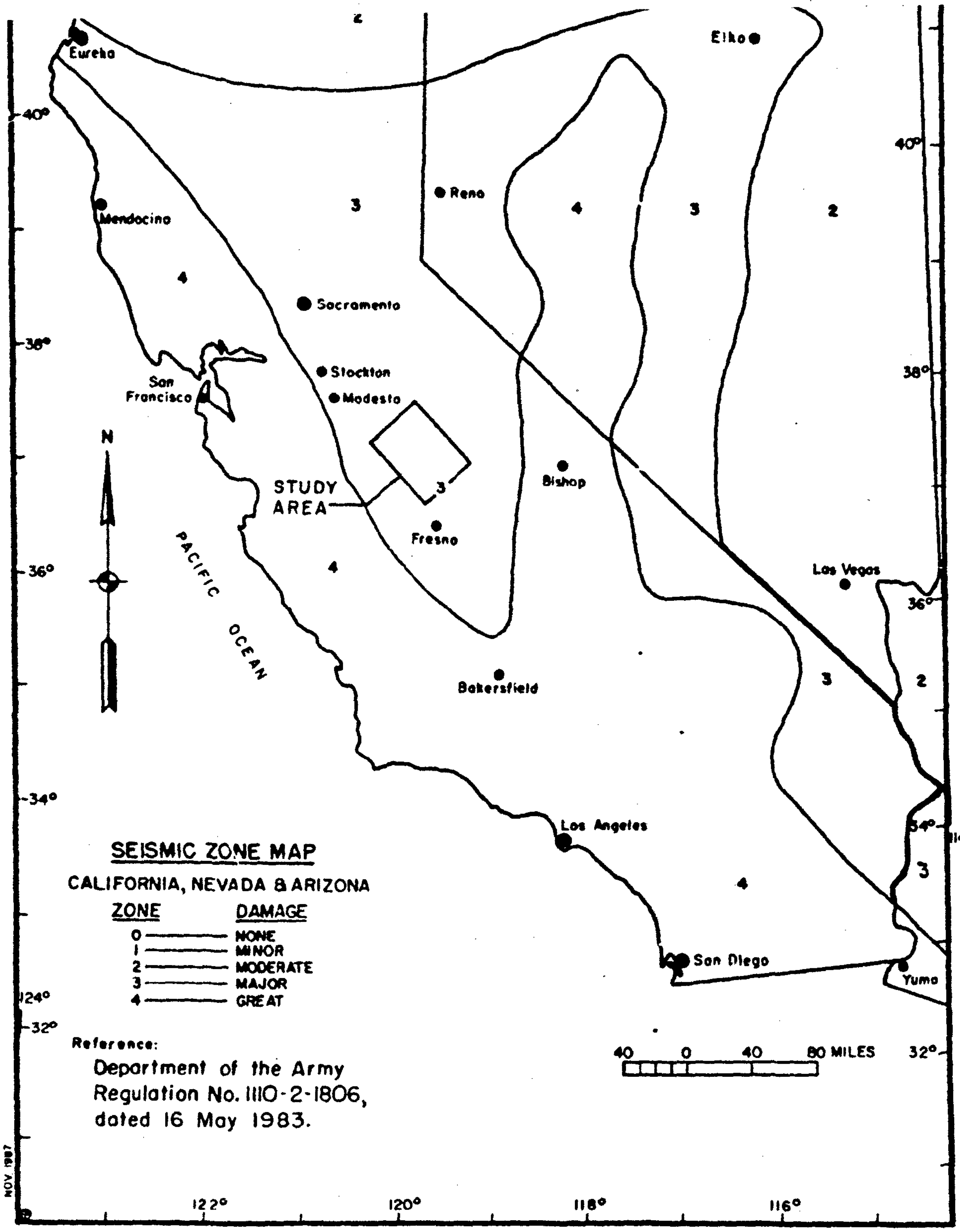
since no faults were found, this lineament is also considered to be of probable fluvial origin and not tectonically controlled.

7 SEISMOLOGY

7.1 Earthquake Database of Historical Seismicity. Hidden and Buchanan Dams lie in Seismic Zone 3 as shown on the Figure 7-1, (Seismic Zone Map). In order to better define the seismic source areas effecting the dams, a site-specific earthquake database for recorded seismic events of M 3.0 and greater was created for a 124-mile (200 km) radius around each of the dams. This information was acquired from the University of California, Berkeley (BERK) and is presented in the form of epicentral plots compiled onto Figures 7-2 and 7-3. The database covers events from January 1910 through October 1988.

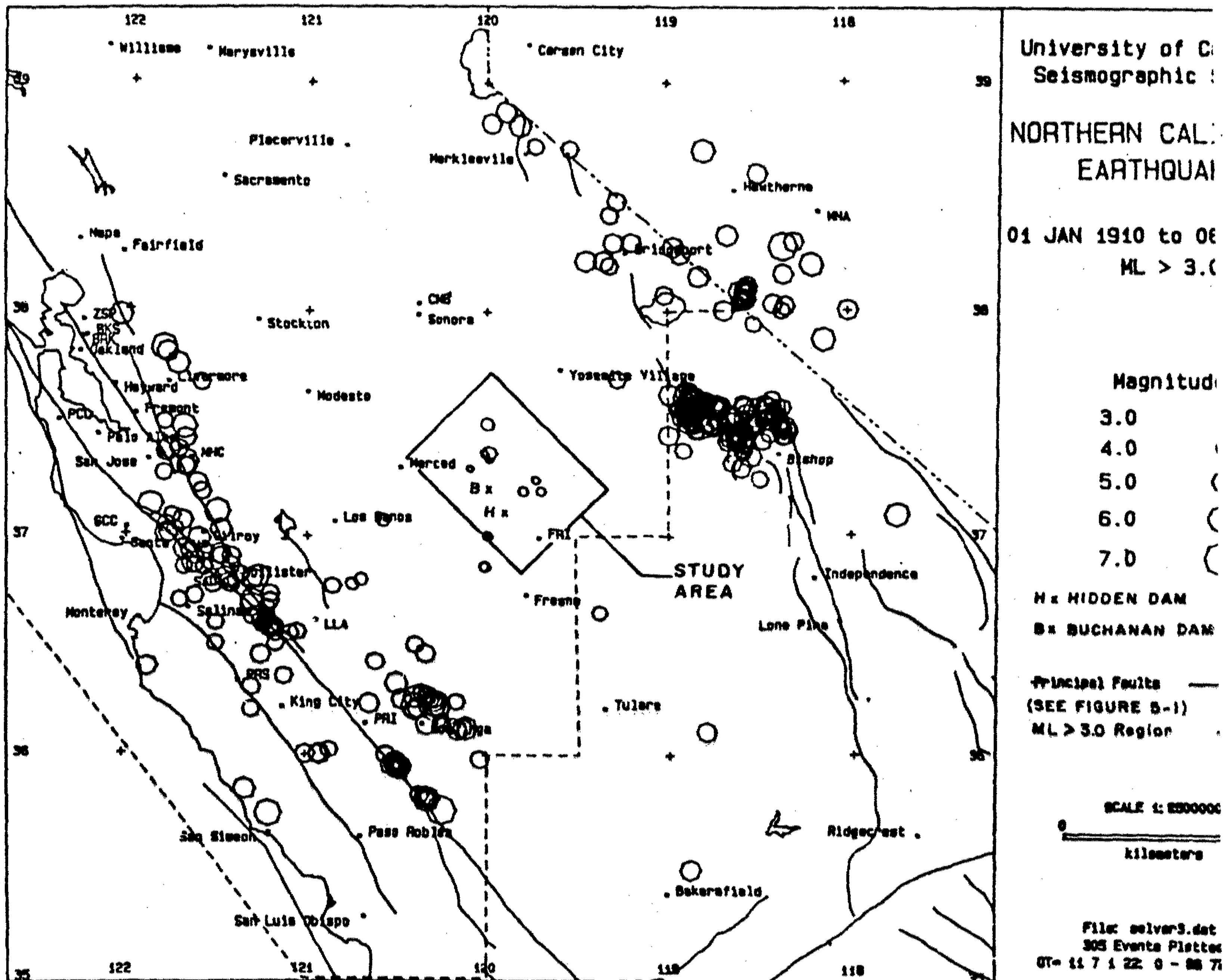
7.1.1 Microseismicity. Microseismicity is defined as earthquake events less than M 3.5. Microseismicity is not a Corps of Engineers criteria for determining fault capability, nor does it produce intensities which cause structural damage as defined by the Modified Mercalli Intensity (MMI) scale. Therefore, microseismicity is only discussed in this report because when these values (M 3.0 to M 3.5) are plotted on Figure 7-2, (Northern California Earthquakes, ML >3.0) their appearance could be misinterpreted as showing fault activity in areas near the dams. Wong and Savage (1983) monitored microseismicity for a study which included the area covered by this investigation and they concluded that these microsiesmic events were confined to the lower crust of the Sierran block at depths from 7.5 miles (12 km) to 23.5 miles (38 km), precluding any association with surficial faults or structures within the Foothills fault system or the Sierra Nevada batholith.

7.1.2 Macroseismicity. Macroseismicity comprises earthquake events of M 3.5 or greater. Historic macroseismic events are shown on Figures 7-2 and 7-3. Events of M 5.0 or greater have energy releases which produce MMI values of VI or greater and can



Eureka
Elko
Mendocino
Reno
Sacramento
Stockton
Modesto
San Francisco
STUDY AREA
Bishop
Fresno
PACIFIC OCEAN
Las Vegas
Bakersfield
Los Angeles
San Diego
Yuma
N
40 0 40 80 MILES
40°
38°
36°
34°
32°
124°
122°
120°
118°
116°
114°
SEISMIC ZONE MAP
CALIFORNIA, NEVADA & ARIZONA
ZONE DAMAGE
0 NONE
1 MINOR
2 MODERATE
3 MAJOR
4 GREAT
Reference:
Department of the Army Regulation No. 1110-2-1806, dated 16 May 1983.
NOV 1987

FIGURE 7-1



University of C
Seismographic
NORTHERN CAL
EARTHQUA
01 JAN 1910 to 0
ML > 3.
Magnitud
3.0
4.0
5.0
6.0
7.0
H x HIDDEN DAM
B x BUCHANAN DAM
Principal Faults
(SEE FIGURE 5-1)
ML > 3.0 Region
kilometers
STUDY AREA
Williams
Marysville
Carson City
Placerville
Sacramento
Markleeville
Hawthorne
Napa
Fairfield
Bridgeport
Stockton
Sonora
Oakland
Livermore
Hayward
Fremont
Modesto
Yosemite Village
Merced
Bishop
San Jose
Los Banos
Gilroy
Hollister
Independence
Monterey
Salinas
LLA
Fresno
Lone Pine
King City
Tulare
San Simeon
Paso Robles
Ridgecrest
Bakersfield
San Luis Obispo
122
121
120
119
118
39
38
37
36
35

FIGURE 7-2

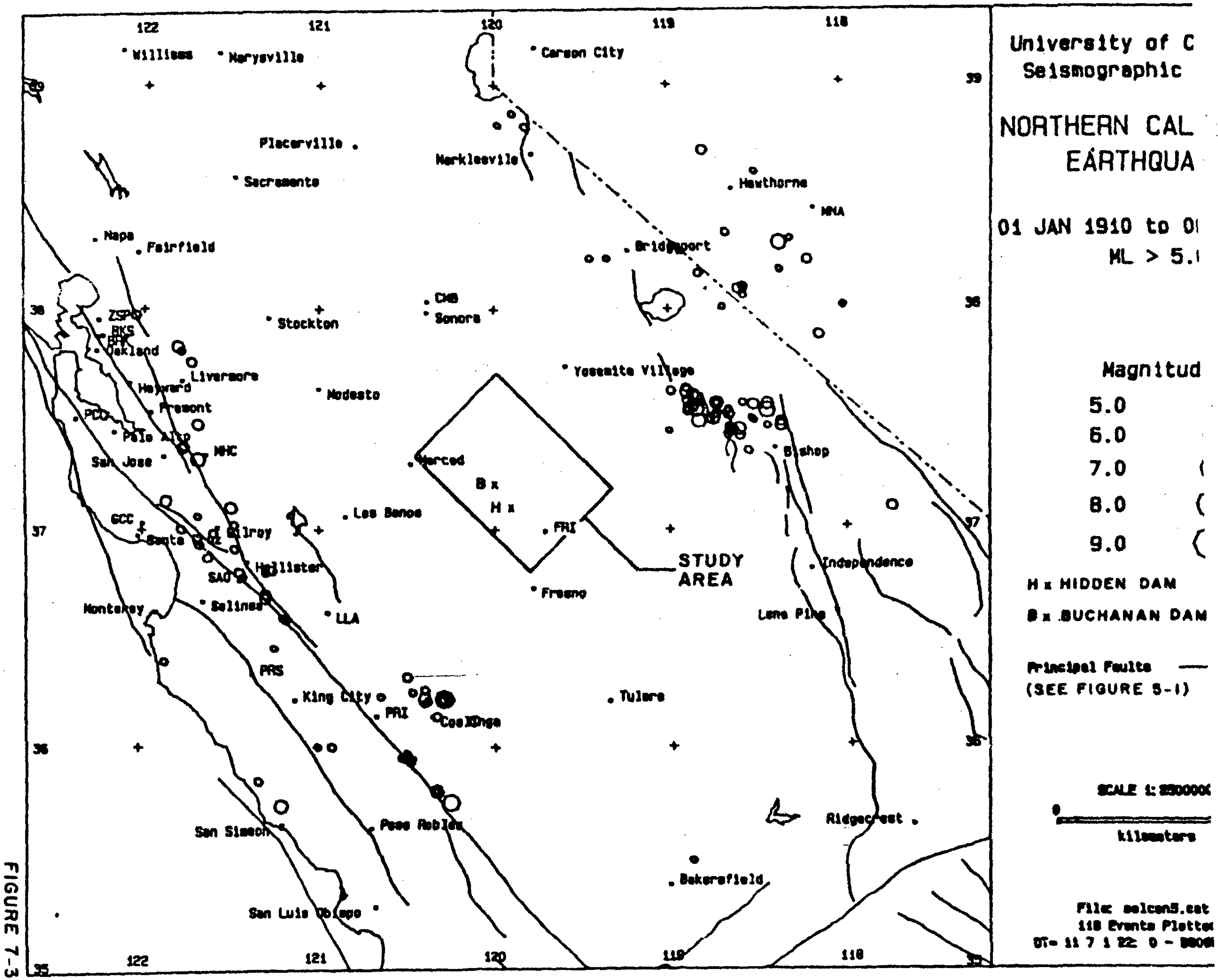

University of C
Seismographic
NORTHERN CAL
EARTHQUA
01 JAN 1910 to 0
ML > 5.
Magnitud
5.0
6.0
7.0
8.0
9.0
H x HIDDEN DAM
B x BUCHANAN DAM
Principal Faults
(SEE FIGURE 5-1)
kilometers
STUDY AREA
Williams
Marysville
Carson City
Placerville
Markleeville
Sacramento
Hawthorne
Napa
Fairfield
Bridgeport
Stockton
Sonoras
Oakland
Livermore
Hayward
Fremont
Modesto
Yosemite Village
Palo Alto
San Jose
Merced
Bishop
Los Banos
Fresno
Independence
Hollister
Monterey
Salinas
LLA
Lone Pine
King City
Coalinga
Tulare
San Simeon
Paso Robles
Ridgecrest
Bakersfield
San Luis Obispo
122
121
120
119
118
39
38
37
36
35

FIGURE 7-3

cause structural damage. As shown on Figure 7-3 (Northern California Earthquakes, ML >5.0) there are no records of historic events of M 5.0 within the study area.

7.2 <u>Seismicity Associated with Known Faults and Fault Systems</u>. Table 7-1 shows the relevant faults and fault systems identified in Chapter 5. Table 7-1 also lists the historic magnitudes associated with these faults, the distance from each event to the dams, and the actual felt intensities in the vicinity of each of the dams. Also included are values of estimated intensities based on Richter magnitudes as arrived at by methods described by Krinitzsky and Chang (1987 and 1975).

<u>Subscripts from Table 7-1</u>:

1. Richter Magnitude
2. Krinitzsky and Chang, 1975, WES: MP S-73-1, Rpt 4, Figure 15, estimate of Modified Mercalli felt Intensity (MMI) Earthquake Scale of 1931 in the vicinity of the dams.
3. Actual felt MMI in the vicinity of the dams.
4. 18 April 1906 "San Francisco Earthquake"
5. 02 May 1983
6. 06 June 1934
7. 27 June 1966
8. Value MMI V is conservative: actual values indicate an event at this distance is below the threshold of minor damage.
9. 26 March 1872 "Owens Valley Earthquake"
10. 27 May 1980
11. 25 May 1980
12. 30 September 1889
13. 01 August 1975 "Oroville Earthquake"
14. 10 August 1975

TABLE 7-1

Hidden And Buchanan Dams

Epicenter Magnitudes, Intensities, And Distances From Dams

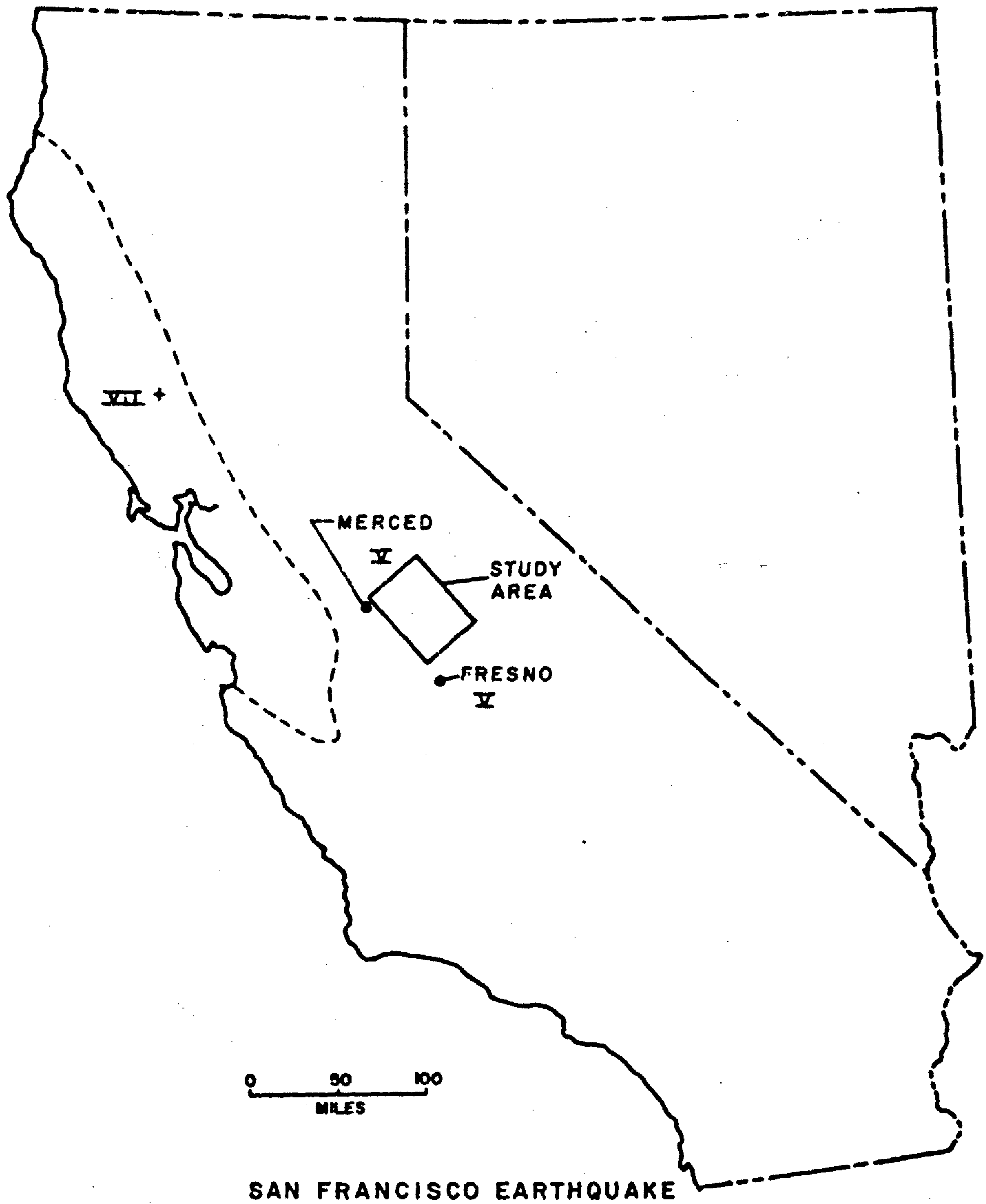
Fault Systems	Town Nearest To Epicenter	Observed Events Mag.[1] (M)	Hidden Dam Dist km	Hidden Dam Est. MMI[2]	Hidden Dam Felt MMI[3]	Buchanan Dam Dist km	Buchanan Dam Est. MMI[2]	Buchanan Dam Felt MMI[3]
San Andreas Fault System	San Fran.	8.3[4]	232	VIII	V	240	VIII	V
	Coalinga	6.7[5]	96	VI	IV	93	VI	IV
	Parkfield	6.0[6] 5.5[7]	168 139	V[8] V[8]	III ≤III	183 163	V[8] V[8]	III ≤III
Sierran Frontal Fault System	Independ.	7.8[9]	171	VII-VIII	VI	182	VII-VIII	VI
	Mammoth Lakes	6.2[10] 6.1[11]	113 113	VI VI	IV IV	120 92	VI VI	IV IV
	Wawona	5.6[12]	70	V[8]	II-IV	113	V[8]	II-IV
Foothills Fault System	Oroville Mariposa	5.7[13] 4.2-4.9[14]	298 34	II-III IV-V	- V	275 18	II-III VI	- V

7.2.1 <u>San Andreas Fault System</u>. The San Andreas fault system is considered by Allen (1968) as capable of a M 8.25 earthquake along the central section. This is a magnitude similar to that of the 1906 San Francisco earthquake. By using the 1906 San Francisco event as an example, MMI values for Hidden and Buchanan Dams were estimated from work by Krinitzsky and Chang (1975) and compared to those actually recorded near the dams. The result

was an estimated MMI of VIII (Table 7-1), however, the isoseismal map of that event (Figure 7-4) prepared by Toppozada and Parke (1982) shows that this area only experienced an MMI of V. Nearer to the dams, seismic events in the Parkfield area on the San Andreas fault and in the Coalinga area (Figure 7-5), which is thought to contain a parallel fault to the San Andreas fault system, have experienced earthquakes of M >6.0 but <7.0. Similarly, the felt intensities in the study area are less than would have been predicted (Table 7-1). Therefore, it seems reasonable that when base rock motions are selected for a seismic evaluation of the dams from earthquakes originating on the San Andreas fault system, they should be scaled to more closely reflect the intensity values actually observed.

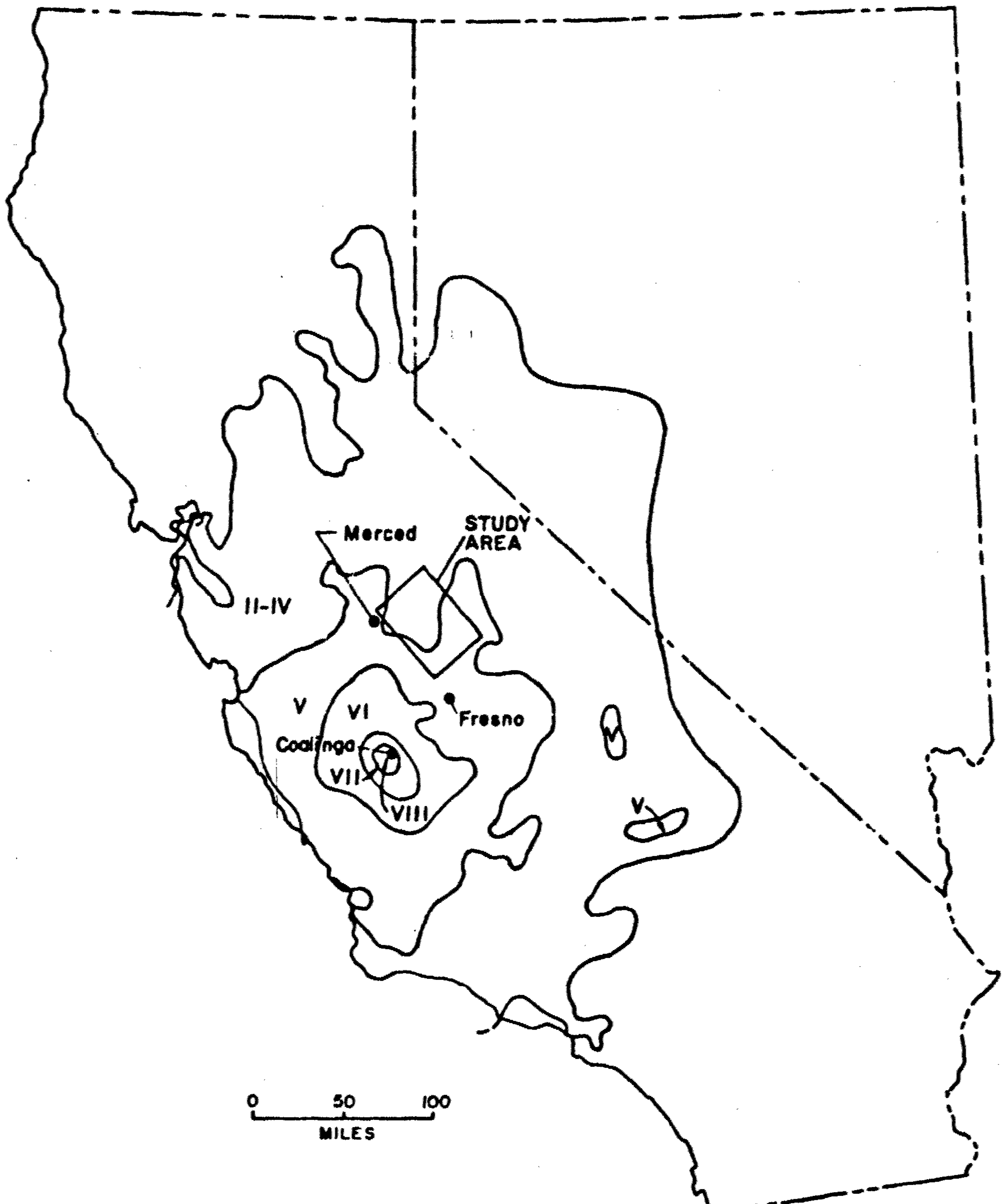
7.2.2 <u>Sierran Frontal (Owens Valley) Fault System</u>. Recent activity on this system nearest to Hidden and Buchanan Dams, has been occurring in the Mammoth Lakes/Long Valley area and in the Chalfant Valley. The Mammoth Lakes area has experienced numerous seismic events of M 6.0 to M 6.9 since 1900. The Chalfant Valley experienced four M 6.0 events in 1980 including that of May 27 (Figure 7-6), and a M 6.1 with associated surface rupture on July 21, 1986 (Kahle, Bryant, and Hart, 1986). The Mammoth Lakes seismic events may be attributable to magmatic activity (Boylan, 1982) rather than Basin and Range extensional faulting, but the events are occurring on the Sierran Frontal fault system.

The Sierran Frontal fault system is generally considered capable of a M 8+ event, based on the Owens Valley earthquake of 1872. Therefore, this system is considered comparable to the San Andreas fault system for seismic activity and hazard potential to Hidden and Buchanan Dams. Again, using Krinitzsky and Chang (1975), estimated MMI values were obtained for the 1872 earthquake in the area of Hidden and Buchanan Dams (Table 7-1). These values indicated a maximum MMI of VII-VIII could be expected at the dams, which is also roughly comparable to the estimated values for the San Andreas fault system. Toppozada, Real, and Parke (1981), however, produced an isoseismal map of the March 26, 1872 event, (Figure 7-7), which shows that the felt



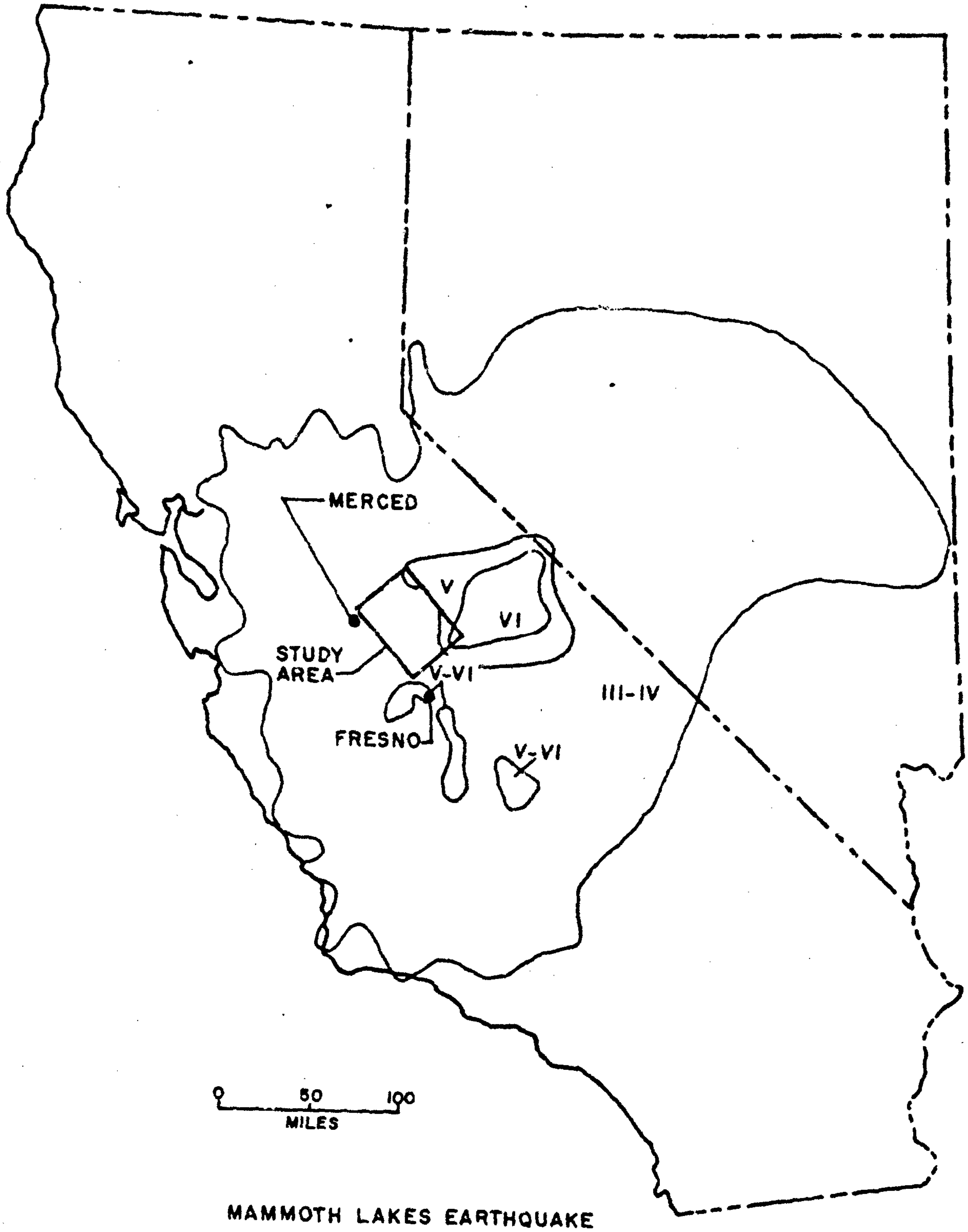
SAN FRANCISCO EARTHQUAKE
MODIFIED MERCALLI INTENSITIES
APRIL 18, 1906
(TOPPOZADA AND PARKE 1982)

FIGURE 7-4



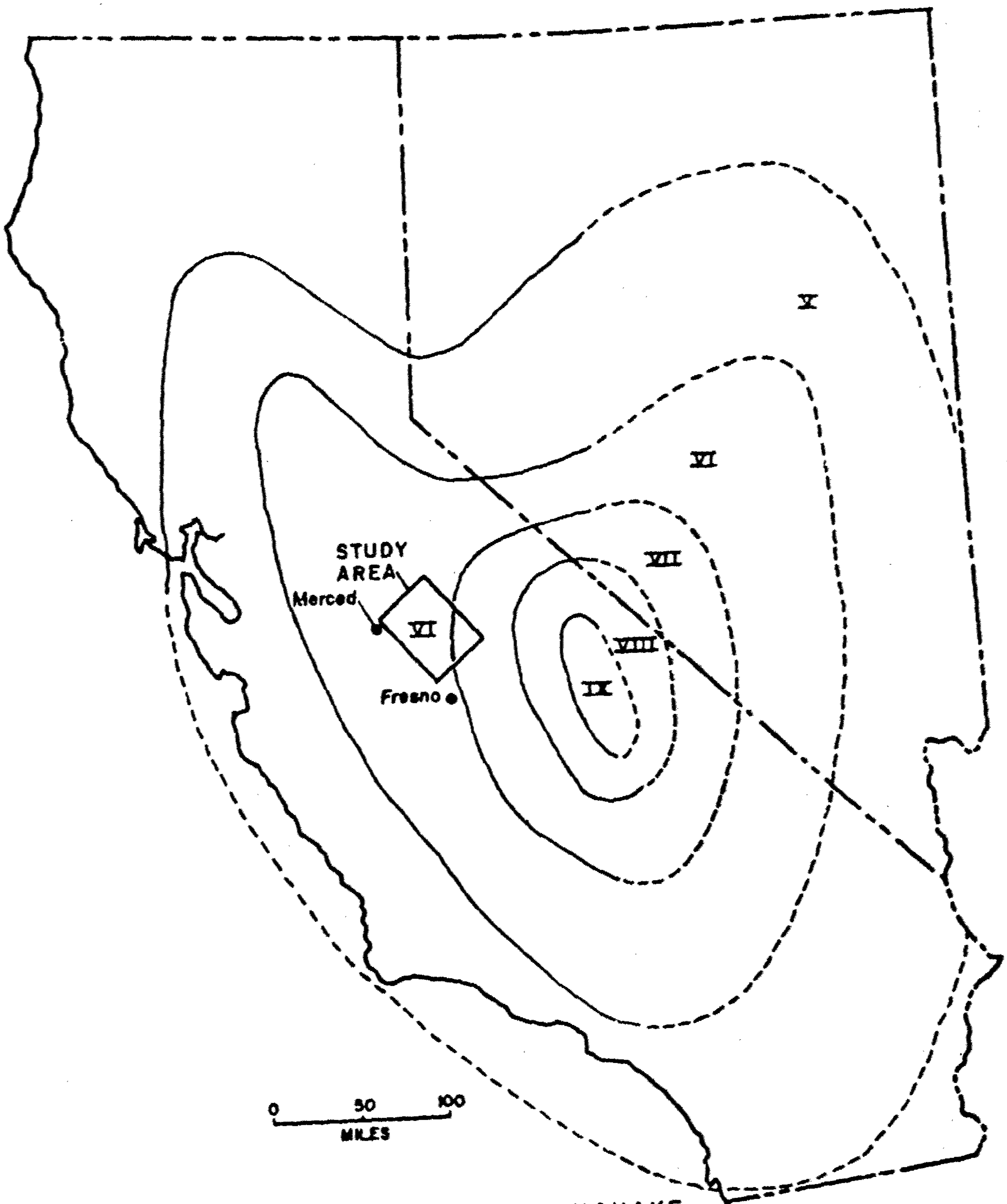
COALINGA EARTHQUAKE
MODIFIED MERCALLI INTENSITIES
MAY 2, 1983
(U.S.G.S. 1983)

FIGURE 7-5



MAMMOTH LAKES EARTHQUAKE
MODIFIED MERCALLI INTENSITIES
MAY 27, 1980
(U.S.G.S. 1982)

FIGURE 7-6



OWENS VALLEY EARTHQUAKE
MODIFIED MERCALLI INTENSITIES
MARCH 26, 1872
(TOPPOZADA AND PARKE 1981)

FIGURE 7-7

San Andreas fault system. Again, it appears that when base rock motions are selected for earthquakes originating on the Sierran Frontal fault system, they should be scaled to more closely reflect the intensities actually felt within the study area.

7.2.3 Foothills Fault System. The August 1, 1975 M 5.7 Oroville earthquake and the resulting ground rupture on the Cleveland Hill fault, approximately 190 miles (305 km) northwest of the study area, resulted in the reclassification of the northern segment of the Foothills fault system as being capable. The southern terminus of this fault system is thought to be just northeast of Hidden and Buchanan Dams and is generally thought to be inactive (Appendix A, pages 29-31) due to the presence of Mesozoic igneous rocks truncating the Melones fault zone and a small Mesozoic pluton breaching the Bear Mountains fault zone. Field reconnaissance of these two fault zones during this study found no surficial evidence to indicate capability within the study area. However, the presence of an August 10, 1975 epicenter of M 4.2 to M 4.9, as reported by the U.S. Dept. of Commerce, 1975 (BERK lists the magnitude as only M 4.2) near the town of Mariposa and just 11 miles (18 km) from Buchanan Dam indicates that a potential for capability may still exist.

Using Krinitzsky and Chang, Report 25 (1987) and Krinitzsky, Chang, and Nuttli, Report 26 (1987) base rock motions were compared for a hypothetical M 6.5 earthquake at the southern end of the mapped trace of the Bear Mountains fault zone and a random M 5.0 earthquake (similar to the reported August 10, 1975 event) at a distance of 6.2 miles (10 km) from either of the dams to those base rock motions similarly derived for the other hypothetical events listed in Table 7-2. The 10 km distance was recommended by professional reviewers O'Neill and James (1988). The motions for a Foothills M 6.5 and a random M 5.0 event did not exceed those determined for the Sierran Frontal fault system. However, a site-specific base rock motion analysis should be performed by a recognized seismologist in order to confirm these

determined capable.

7.3 Seismic Source Areas. In addition to using the actual felt MMI values generated by each source area, the base rock motions for Hidden and Buchanan Dams should be further refined using the hypothetical epicentral magnitudes and the distances to the causative faults, fault zones, and source areas as shown on Table 7-2:

Table 7-2

Epicenter Source, Maximum Magnitude, and Distance to Dams

SOURCE	MAXIMUM EPICENTER MAGNITUDE (M)	DISTANCE (km) TO HIDDEN DAM	DISTANCE (km) TO BUCHANAN DAM
San Andreas	8.25	112	124
Sierran Frontal	8.0+	112	120
Coalinga	7.0	96	93
Foothills	6.5	50	35
Random	5.0	10	10

7.4 Seismic Criteria. Hidden and Buchanan Dams are founded on a combination of metamorphic and granitic bedrock. This gives each dam a rock or "hard site" classification for determining ground motions. As shown in Table 7-1, methods of estimating or predicting site intensities for the dams resulted in conservative values of 1 to 2 levels of intensity greater than are actually felt at either of the sites. If these conservative values are used in the dynamic response analyses of the dams, they will

... is the norm for similar structures in similar seismic localities. Therefore, the base rock motions should be developed to accurately reflect the attenuation characteristics of the source areas as modified by the site and regional geology and expressed by the actual MMI values felt at the dams. Only then will it be possible for a seismologist to select analogous time histories, response spectra, and scaling factors.

A probabilistic study of earthquake hazard should also be conducted to determine the percent probability of exceeding the calculated base rock motions. This would further help in refining the values used for the design and operational earthquakes from those calculated for the maximum credible earthquake.

The above determinations should be accomplished by a seismologist who is a recognized authority on California and western United States earthquakes.

8 FINDINGS AND CONCLUSIONS

8.1 Findings. Trenches were excavated across photolineaments at Sites 1, 3, and 5. Trenches were excavated across inferred faults at Sites 2, 4, and 6. Site 6 crossed what was also referred to as the "County Line Lineament." The results of investigations for this report revealed the following:

8.1.1 Photolineaments.

1. The primary photolineament set has a regional trend of N20°W to N50°W. similar to the strikes of the Tertiary Ione, Valley Springs, Mehrten, and Laguna Formations.

2. These photolineaments generally conform to topographic lows, such as aligned swales and linear valleys.

3. No evidence of faulting was found in trench excavations across the photolineaments (Sites 1, 3, and 5).

4. Evaluation of trench logs indicates that the photolineaments are the result of fluvial processes, possibly influenced by regional joint sets reflected in the Tertiary and Quaternary formations from underlying bedrock (PG&E, 1977).

5. The photolineaments detected by the imagery analysis are underlain by Quaternary formations which are undisturbed, further indicating that there has been no seismotectonic movement from the present to at least 100,000 years ago and possibly to 400,000 years ago.

8.1.2 Inferred Faults.

1. The features inferred as faults at Sites 2 and 6 were mapped as having a similar regional trend as that of the photolineaments. The one mapped at Site 4 did not.

2. The features at Sites 2 and 4 are located on topographic highs, uplands and hilltops. At Site 6 it is located in a topographic low, or swale.

3. No fault was located at Site 2. Fluvial processes account for the apparent discontinuous bedding visible in the roadcut on Avenue 15.

4. No fault was located at Site 4 along Avenue 24. The Quaternary formations overlying the site are not disturbed. Some of the layers do exhibit localized cracks or possibly what was referred to as joints in trench excavations conducted for PG&E (1977). These cracks often weather unevenly and may be what was inferred to have been a fault at this site.

5. No fault was located at Site 6 in the Quaternary sediments or in the underlying bedrock. The Quaternary sediments are not as diagnostic for age determinations at this site, but the lack of bedrock faulting negates this requirement.

8.2 Conclusions.

1. No capable faults were found within the geologic and seismologic investigation area for Hidden and Buchanan Dams.

2. Subsurface investigations performed in this study found no evidence to substantiate the existence of three inferred faults mapped by Marchand (1976a-f) and Marchand and Allwardt (1978, and 1981).

3. The San Andreas fault system and the Sierran Frontal (Owens Valley) fault system are the most likely sources

historically of M > 6.5 seismic events which will have the greatest felt intensities at Hidden and Buchanan Dams.

4. A hypothesized M 6.5 event on the Foothills fault system at approximately 31 miles (50 km) and 22 miles (35 km) from Hidden and Buchanan, respectively, and a random M 5.0 event at a distance of 6.2 miles (10 km) from each dam should be evaluated to confirm that their base rock motions will not exceed the seismic design criteria for the maximum credible earthquake which could occur on either the San Andreas fault system or the Sierran Frontal fault system.

5. The seismic design criteria for the maximum design earthquake should be scaled from accelerograms of events in similar geologic regions as selected by a recognized authority on California seismology.

BIBLIOGRAPHY

Allen, C.R., 1968, THE TECTONIC ENVIRONMENTS OF SEISMICALLY ACTIVE AND INACTIVE AREAS ALONG THE SAN ANDREAS FAULT SYSTEM: Stanford University Pub. Geol. Sci. Vol.11, pp.70-92.

___________, 1981, THE MODERN SAN ANDREAS: in The Geotectonic Development of California, Vol.I, W.G. Ernst, Editor; Englewood Cliffs, Prentice-Hall, pp.511-534.

Anttonen, G.J., et al, 1974, THE KINGS CANYON LINEAMENT; A CROSS-GRAIN ERTS-1 LINEAMENT IN CENTRAL CALIFORNIA: in 1974 Basement Tectonics Contribution No.9 pp. 81-93.

Arkley, R.J., 1954, SOILS OF EASTERN MERCED COUNTY, CALIFORNIA: California Department of Soils and Plant Nutrition, University of California, Berkeley, 174p.

___________, 1962a, THE GEOLOGY, GEOMORPHOLOGY, AND SOILS OF THE SAN JOAQUIN VALLEY IN THE VICINITY OF THE MERCED RIVER, CALIFORNIA: in Geologic Guide to the Merced Canyon and Yosemite Valley, California, California Division of Mines and Geology, Bulletin 182, pp.25-32.

___________, 1962b, SOIL SURVEY, MERCED COUNTY, CALIFORNIA: U.S. Department of Agriculture, Soil Conservation Service, Series 1950, No.7.

Atwater, T., 1970, IMPLICATIONS OF PLATE TECTONICS FOR THE CENOZOIC TECTONIC EVOLUTION OF WESTERN NORTH AMERICA: in Geological Society of America Bulletin, Vol.81, No. 12, pp. 3513-3535, illus.

Bateman, D.C., Buscana, A.J., Marchand, D.E., and Sauka, W.N., 1983, GEOLOGIC MAP OF THE RAYMOND QUADRANGLE, MADERA AND MARIPOSA COUNTIES, CALIFORNIA: U.S. Geological Survey Quadrangle Map GQ-1555.

Berggren, W.A., 1972, A CENOZOIC TIME SCALE, SOME IMPLICATIONS FOR REGIONAL GEOLOGY AND PALEOBIOGEOGRAPHY: Lethaia, Vol.5, No.2, pp195-215.

Boylan, R.T.,1982, MAMMOTH LAKES/LONG VALLEY MICROEARTHQUAKE PROJECT, in California Geology: Division of Mines and Geology, Vol.35 No.9, pp.187-190.

Burnett, J. L., 1976, KAWEAH PEAKS PLUTON AND ITS RELATIONSHIP TO THE AGE OF THE KERN CANYON FAULT, TULARE COUNTY, CALIFORNIA: California Division of Mines and Geology Map Sheet 35.

Busby-Spera, C.J., 1980, EARLY MESOZOIC QUARTZ SANDSTONE-VOLCANIC ARC ASSOCIATIONS IN THE KAWEAH RIVER AREA, SOUTHERN SIERRA NEVADA, CALIFORNIA: Cordilleran Section, Geological Society of America Abstracts with programs, pp.99-100.

Butler, C.S., and Jones, G.S. 1974, SOIL SURVEY OF MARIPOSA COUNTY AREA, CALIFORNIA, U.S. Department of Agriculture, Soil Conservation Service. 68p.

Cady J.W., 1975, MAGNETIC AND GRAVITY ANOMALIES IN THE GREAT VALLEY AND WESTERN SIERRA NEVADA METAMORPHIC BELT, CALIFORNIA: Geological Society of America Special Paper 168, 56p.

Carder, D.S., 1973, TRANS-CALIFORNIA SEISMIC PROFILE, DEATH VALLEY TO MONTEREY BAY: Bulletin of the Seismological Society of America, Vol.63, No.2, pp.571-586.

Clark, L.D., 1960, FOOTHILLS FAULT SYSTEM, WESTERN SIERRA NEVADA, CALIFORNIA: Bulletin of the Geological Society of America, Vol.71 pp.483-496.

Croft, and Gordon, 1968, GEOLOGY, HYDROLOGY, AND QUALITY OF WATER IN THE HANFORD-VISALIA AREA: U.S. Geological Survey Open file Report,

Dalrymple, G.B., 1963, POTASSIUM-ARGON DATES OF SOME CENOZOIC VOLCANIC ROCKS IN THE SIERRA NEVADA, CALIFORNIA: Geological Society of America Bulletin, Vol.74, pp.379-390.

Davis, S.N., and Hall, F.R., 1959, WATER QUALITY OF EASTERN STANISLAUS AND NORTHERN MERCED COUNTIES, CALIFORNIA: Stanford University Publications, Geological Sciences, Vol.6, No.1, 112p.

Dibblee, T.W., Jr., 1966, EVIDENCE FOR CUMULATIVE OFFSET ON THE SAN ANDREAS FAULT IN CENTRAL AND NORTHERN CALIFORNIA: in Geology of Northern California; California Division of Mines and Geology Bulletin 190, pp.375-384.

Dickinson, W.R., 1981, PLATE TECTONICS AND THE CONTINENTAL MARGIN OF CALIFORNIA, in the Geotectonic Development of California, Vol.I, W.G. Ernst, Editor; Englewood Cliffs, Prentice-Hall, pp.1-28.

Duffield, W.A., and Sharp R.V., 1975, GEOLOGY OF THE SIERRA FOOTHILLS MELANGE AND ADJACENT AREAS, AMADOR COUNTY, CALIFORNIA: U.S. Geological Survey Professional Paper 827, 30p.

Greensfelder, R.W., 1974, MAXIMUM CREDIBLE ROCK ACCELERATION FROM EARTHQUAKES IN CALIFORNIA: California Division of Mines and Geology, Map Sheet 23, 12p.

Hall, C.A. Jr., 1981, EVOLUTION OF THE WESTERN TRANSVERSE RANGES MICROPLATE: LATE CENOZOIC FAULTING AND BASINAL DEVELOPMENT: in The Geotectonic Development of California, Vol.I, W.G. Ernst, Editor; Englewood Cliffs, Prentice-Hall, pp.559-582.

Harlan Miller Tait, 1987, PHOTOGEOLOGIC INTERPRETATION AND IMAGERY ANALYSIS, HIDDEN AND BUCHANAN DAMS NEAR MERCED. CALIFORNIA: Unpublished report prepared by Dr. R.H. Wright, for Sacramento District, United States Army Corps of Engineers, 53p.

Helley, E.J., 1967, SEDIMENT TRANSPORT IN THE CHOWCHILLA RIVER BASIN: MARIPOSA, MADERA AND MERCED COUNTIES, CALIFORNIA: Ph.D. Dissertation, University of California, Berkeley, 153p.

Hodges, C.A., 1979, PRELIMINARY MAPS OF PHOTOLINEAMENTS ALONG PARTS OF THE WESTERN SIERRA NEVADA FOOTHILLS AND EASTERN COAST RANGE FOOTHILLS, CALIFORNIA, BASED ON LANDSAT IMAGES AND U-2 AIRCRAFT PHOTOGRAPHS: U.S. Geological Survey Open-File Report 79-1470, scale 1:250,000 8p.

Janda, R.J., 1965, QUATERNARY ALLUVIUM NEAR FRIANT, CALIFORNIA: International Association Quaternary Research Guidebook for field Conference 1, Northern Great Basin and California, pp.128-133.

___________, 1966, PLEISTOCENE HISTORY AND HYDROLOGY OF THE UPPER SAN JOAQUIN RIVER, CALIFORNIA: Ph.D. Dissertation, University of California, Berkeley, 459p.

Janda, R.J., and Croft, M.G., 1967, THE STRATIGRAPHIC SIGNIFICANCE OF A SEQUENCE OF NONCALCIC BROWN SOILS FORMED ON THE QUATERNARY ALLUVIUM OF THE NORTHEASTERN SAN JOAQUIN VALLEY, CALIFORNIA: in International Association Quaternary Research, Quaternary Soils: Internat. Assoc. Quaternary Research, VII Cong., Reno, Nev., Proc., Vol.9, pp.158-190.

Jennings, C.W., 1975, FAULT MAP OF CALIFORNIA: California Division of Mines and Geology, California Geologic Data Map Series, Map No. 1.

Jones, L.M., and Dollar, R.S., 1986, EVIDENCE OF BASIN-AND-RANGE EXTENSIONAL TECTONICS IN THE SIERRA NEVADA; THE DURWOOD MEADOWS SWARM, TULARE COUNTY, CALIFORNIA (1983-1984): Bulletin of the Seismological Society of America, Vol. 76, No.2, pp.439-461.

Kahle, J.E., Bryant, W.A., and Hart, E.W., 1986, CHALFANT VALLEY EARTHQUAKE, in California Geology: Division of Mines and Geology, Vol.39, No.11, pp.243-245.

King, P.B., 1977, THE EVOLUTION OF NORTH AMERICA: Princeton, Princeton University Press, 197p.

Krinitzsky, E.L., and Chang, F.E., 1975, STATE-OF-THE-ART FOR ASSESSING EARTHQUAKE HAZARDS IN THE UNITED STATES, REPORT 4, EARTHQUAKE INTENSITY AND THE SELECTION OF GROUND MOTIONS FOR SEISMIC DESIGN: U.S. Army Engineer Waterways Experiment Station, Miscellaneous Paper S-73-1, Vicksburg, Mississippi.

__________________________________, 1987, STATE-OF-THE-ART FOR ASSESSING EARTHQUAKE HAZARDS IN THE UNITED STATES, REPORT 25, PARAMETERS FOR SPECIFYING INTENSITY-RELATED EARTHQUAKE GROUND MOTIONS: U.S. Army Engineer Waterways Experiment Station, Miscellaneous Paper S-73-1, Vicksburg, Mississippi, 43p.

Krinitzsky, E.L., Chang, F.E. and Nuttli, O.W., 1987, STATE-OF-THE-ART FOR ASSESSING EARTHQUAKE HAZARDS IN THE UNITED STATES, REPORT 26, PARAMETERS FOR SPECIFYING MAGNITUDE-RELATED EARTHQUAKE GROUND MOTIONS: U.S. Army Engineer Waterways, Experiment Station, Miscellaneous Paper S-73-1, Vicksburg, Mississippi, 57p.

Leeds, D.J., 1980, SEISMIC CRITERIA, SUCCESS DAM, PORTERVILLE, TULARE COUNTY, CALIFORNIA: in 1983, Dynamic Analysis of Success Dam, Department of the Army, Sacramento, District, Corps of Engineers, Appendix A.

___________, 1980, SEISMIC CRITERIA, TERMINUS DAM, TULARE COUNTY CALIFORNIA: in 1983, Dynamic Analysis of Terminus Main and Auxiliary Dams, Department of the Army, Sacramento District Corps of Engineers, Appendix A.

Loomis, D.P., and Glazner, A.F., 1982, EFFECTS OF FARALLON PLATE SUBDUCTION ON MIOCENE EVOLUTION OF THE SAN JOAQUIN BASIN, CALIFORNIA, Geological Society of America Abstracts with Programs, Vol.14, No.7, p.549.

Los Angeles City, Department of Water and Power, 1975, SAN JOAQUIN NUCLEAR PROJECT, EARLY SITE REVIEW REPORT: (Unpublished ?).

Mack, S., and Schmidt, K.D., 1981, HYDROGEOLOGY OF THE SIERRA NEVADA FOOTHILL LINEAMENT NEAR OAKHURST, CALIFORNIA: Ground Water, Vol.19, No.2, pp.149-155.

Mathews, R.A., and Burnett, J.L., 1965, GEOLOGIC MAP OF CALIFORNIA, OLAF P. JENKINS EDITION, FRESNO SHEET: California Division of Mines and Geology, scale 1:250,000.

Marchand, D.E., 1976a, PRELIMINARY GEOLOGIC MAPS SHOWING QUATERNARY DEPOSITS OF THE MERCED AREA, EASTERN SAN JOAQUIN VALLEY, MERCED COUNTY, CALIFORNIA: U.S. Geological Survey Open-File Series 76-837, 7 sheets, scale 1:24,000.

________, 1976b, PRELIMINARY GEOLOGICAL MAPS SHOWING QUATERNARY DEPOSITS OF THE MADERA AREA, EASTERN SAN JOAQUIN VALLEY, MADERA AND FRESNO COUNTIES, CALIFORNIA: U.S. Geological Survey Open-File Report 76-841, 8 sheets, scale 1:24,000 and report, 12p.

________, 1976c, PRELIMINARY GEOLOGIC MAPS SHOWING QUATERNARY DEPOSITS OF THE CHOWCHILLA AREAS, EASTERN SAN JOAQUIN VALLEY, MADERA AND MERCED COUNTIES, CALIFORNIA: U.S. Geological Survey Open-File Series 76-839, 5 sheets, scale 1:24,000.

________, 1976d, PRELIMINARY GEOLOGIC MAPS SHOWING QUATERNARY DEPOSITS OF THE NORTHERN MERCED AREA, EASTERN SAN JOAQUIN VALLEY, MERCED AND STANISLAUS COUNTIES, CALIFORNIA: U.S. Geological Survey, Open-File Series 76-836, 8 sheets, scale 1:24,000.

________, 1976e, PRELIMINARY GEOLOGIC MAPS SHOWING QUATERNARY DEPOSITS OF THE PAULTON AREA, EASTERN SAN JOAQUIN VALLEY, MADERA COUNTY, CALIFORNIA: U.S. Geological Survey, Open-File Report 76-840, 4 sheets, scale 124,000 and report, 12p.

________, 1976f, PRELIMINARY GEOLOGIC MAPS SHOWING QUATERNARY DEPOSITS OF THE SOUTHERN MERCED AREA, EASTERN SAN JOAQUIN VALLEY, MERCED AND MADERA COUNTIES, CALIFORNIA: U.S. Geological Survey Open-File Series 76-838, 7 sheets, scale 1:24,000.

________, 1977, THE CENOZOIC HISTORY OF THE SAN JOAQUIN VALLEY AND THE ADJACENT SIERRA NEVADA AS INFERRED FROM THE GEOLOGY AND SOILS OF THE EASTERN SAN JOAQUIN VALLEY: in Singer, M.S., Ed., SOIL DEVELOPMENT, GEOMORPHOLOGY, AND CENOZOIC HISTORY OF THE NORTHEASTERN SAN JOAQUIN VALLEY AND ADJACENT AREAS, CALIFORNIA: University of California, Davis, Guidebook for Joint Field Session, Soil Science Society of America and Geological Society of America, p.39-50.

Marchand, D.E., and Allwardt, A., 1978, QUATERNARY DEPOSITS, NORTHEASTERN SAN JOAQUIN VALLEY, CALIFORNIA: U.S. Geological Survey Miscellaneous Field Studies Map MF-945, scale 1:125,000.

______________________________, 1981, LATE CENOZOIC STRATIGRAPHIC UNITS, NORTHEASTERN SAN JOAQUIN VALLEY, CALIFORNIA: U.S. Geological Survey Bulletin 1470, 70p.

Moore, J.G, et al, 1979, GEOLOGIC GUIDE TO THE KINGS CANYON HIGHWAY, CENTRAL SIERRA NEVADA, CALIFORNIA: Geological Society of America, Cordilleran Section 75th Annual Meeting, 33p.

Moore, J.G., and Dodge, C.W., 1980, LATE CENOZOIC VOLCANIC ROCKS OF THE SOUTHERN SIERRA NEVADA, CALIFORNIA: Geological Society of America Bulletin Part II, Vol.91, pp.1995-2038.

Nokleberg, W.J., 1983, WALLROCKS OF THE CENTRAL SIERRA NEVADA BATHOLITH, CALIFORNIA; A COLLAGE OF ACCRETED TECTONO-STRATIGRAPHIC TERRANES: U.S. Geological Survey Professional Paper 1255, 29p. 1 folded map.

Norris, R.M. and Webb, R.W., 1976, GEOLOGY OF CALIFORNIA: New York, Wiley and Sons Inc., 361 p.

Oakeshott, G.B., Greensfelder R.W., and Kahle, J.E., 1972, ONE-HUNDRED YEARS LATER, 1872-1972: in California Geology, Vol. 25, No. 3, pp.55-61.

Pacific Gas and Electric Company, (1977), NOTICE OF INTENTION OF STANISLAUS NUCLEAR PROJECT ALTERNATE SITES: MERCED, MADERA: submitted to California State Energy Resources Conservation and Development Commission, Vol.I and II.

Page, B.M., 1981, THE SOUTHERN COAST RANGES in The Geotectonic Development of California, Vol.I, W.G. Ernst, Editor; Englewood Cliffs, Prentice-Hall, pp.329-418.

Paterson, S.R., Tobisch, J.K., and Radloff, J.K., 1987, POST-NEVADAN DEFORMATION ALONG THE BEAR MOUNTAINS FAULT ZONE: IMPLICATIONS FOR THE FOOTHILLS TERRANE, CENTRAL SIERRA NEVADA, CALIFORNIA: Geology, Vol.15, pp.513-516.

Poland, J.F., et al, 1975, LAND SUBSIDENCE IN THE SAN JOAQUIN VALLEY, CALIFORNIA: U.S. Geological Survey Professional Paper 437-H, 77p.

Rodgers, T.H., 1966, GEOLOGIC MAP OF CALIFORNIA: OLAF P. JENKINS EDITION, SAN JOSE SHEET: California Division of Mines and Geology, scale 1:250,000.

... KINGS CANYON NATIONAL PARKS, CALIFORNIA: California Division of Mines and Geology Special Report 53, 24p.

Rutherford and Chekene, 1987, PHOTOGEOLOGIC INTERPRETATION AND IMAGERY ANALYSIS, SUCCESS AND TERMINUS DAMS CALIFORNIA: prepared for the Sacramento District, United States Army Corps of Engineers by Allen D. Bailey, 17 p. and Appendix by Roy J. Shlemon PhD. (Unpublished).

Saleeby, J.B., 1975, STRUCTURE, PETROLOGY, AND GEOCHRONOLOGY OF THE KINGS-KAWEAH MAFIC-ULTRAMAFIC BELT, SOUTHWESTERN SIERRA NEVADA FOOTHILLS, CALIFORNIA: University of California, Santa Barbara, Ph.D. Dissertation (unpublished).

_____________, 1977, FIELDTRIP GUIDE TO THE KINGS-KAWEAH SUTURE, SOUTHWESTERN SIERRA NEVADA FOOTHILLS, CALIFORNIA: Geological Society of America, Cordilleran Section, 47p.

_____________, 1978, PALEO-BASEMENT GEOLOGY OF THE SIERRA NEVADA FOOTHILL METAMORPHIC BELT AND ITS IMPLICATIONS ON THE NEVADAN OROGENY: Geological Society of America, Cordilleran Section, Abstracts with Programs, p.145.

_____________, 1978, KINGS RIVER OPHIOLITE, SOUTHWESTERN SIERRA NEVADA FOOTHILLS, CALIFORNIA: Geological Society of America Bulletin, Vol.89 pp.617-636.

_____________, 1979, KAWEAH SERPENTINITE MELANGE, SOUTHWEST SIERRA NEVADA FOOTHILLS, CALIFORNIA: Geological Society of America Bulletin, Vol.90 pp.29-46.

Saleeby, J.B., and Sharp, W., 1980, CHRONOLOGY OF THE STRUCTURAL AND PETROLOGIC DEVELOPMENT OF THE SOUTHWEST SIERRA NEVADA FOOTHILLS, CALIFORNIA: Geological Society of America Bulletin, Vol. 91, pp.317-320.

Schweickert, R.A., 1978, TRIASSIC & JURASSIC PALEOGEOGRAPHY OF THE SOUTHWESTERN SIERRA NEVADA AND ADJACENT REGIONS, CALIFORNIA AND WESTERN NEVADA: in Mesozoic Paleogeography of the Western United States, Pacific Coast Paleogeography Symposium II, Howell & McDougall, Editors.

_________________, 1981, TECTONIC EVOLUTION OF THE SIERRA NEVADA RANGE, in The Geotectonic Development of California, Vol.I, W.G. Ernst, Editor; Englewood Cliffs, Prentice-Hall, pp.87-181.

CALIFORNIA: in Paleozoic Paleogeography of the Western United States, J. Stewart, et al, editors; Society of Economic Paleontologists and Minerologists, Pacific Section, pp.381-394.

Schweickert, R.A., et al, 1984, TIMING AND STRUCTURAL EXPRESSION OF THE NEVADAN OROGENY, SIERRA NEVADA, CALIFORNIA, Geological Society of America Bulletin, Vol. 95, pp.967-979.

Seed, and Idriss, 1983, GROUND MOTION AND SOIL LIQUIFACTION DURING EARTHQUAKES, Earthquake Engineering Research Institute, 134p.

Shlemon, R.J., 1985, APPLICATION OF SOIL-STRATIGRAPHIC TECHNIQUES TO ENGINEERING GEOLOGY: Association of Engineering Geologist Bulletin Vol.XXII, No.2, pp.129-142.

______________, 1986, SOIL-STRATIGRAPHIC AND GEOMORPHIC RECONNAISSANCE: FAULT INVESTIGATION, SUCCESS AND TERMINUS DAMS, EAST-CENTRAL SAN JOAQUIN VALLEY, CALIFORNIA: Unpublished summary report prepared for Sacramento District, United States Army Corps of Engineers.

______________, 1986, AGE OF QUATERNARY SEDIMENTS AND SOILS, FAULT STUDY TRENCHES: Unpublished summary report prepared for Sacramento District, United States Army Corps of Engineers.

______________, 1988, AGE OF QUATERNARY SEDIMENTS AND SOILS, FAULT AND LINEAMENT INVESTIGATIONS. MADERA AND MERCED COUNTIES, CALIFORNIA: Unpublished summary report prepared for Sacramento District, United States Army Corps of Engineers.

Strand, R.S., 1967, GEOLOGIC MAP OF CALIFORNIA, OLAF P. JENKINS EDITION, MARIPOSA SHEET: California Division of Mines and Geology, scale 1:250,000.

Toppozada, T.R., Real, C.R., and Parke, D.L., 1981, PREPARATION OF ISOSEISMAL MAPS AND SUMMARIES OF REPORTED EFFECTS FOR PRE-1900 CALIFORNIA EARTHQUAKES: California Division of Mines and Geology, Open-File Report 81-11 SAC, 182p.

Toppozada, T.R., and Parke, D.L., 1982, AREAS DAMAGED BY CALIFORNIA EARTHQUAKES, 1900-1949: California Division of Mines and Geology, Open-File Report 82-17 SAC, 65p.

U.S. Army Corps of Engineers, 1977, FOUNDATION REPORT, HIDDEN DAM PROJECT, HENSLEY LAKE, FRESNO RIVER, CALIFORNIA: U.S. Army Corps of Engineers, Sacramento District, 79p.

-----------------------------, 1977, FOUNDATION REPORT, BUCHANAN DAM PROJECT, H.V. EASTMAN LAKE, CHOWCHILLA RIVER, CALIFORNIA: U.S. Army Corps of Engineers, Sacramento District, 62p.

-----------------------------, 1979, GEOLOGIC RECONNAISSANCE OF THE KINGS-KAWEAH SUTURE: U.S. Army Corps of Engineers, Sacramento District, 11p.

-----------------------------, 1985a, GEOLOGIC RECONNAISSANCE OF THE BUCHANAN DAM AND EASTMAN LAKE AREA: U.S. Army Corps of Engineers, Sacramento District, 7p.

-----------------------------, 1985b, GEOLOGIC RECONNAISSANCE OF THE HIDDEN DAM AND HENSLEY LAKE AREA: U.S. Army Corps of Engineers, Sacramento District, 7p.

U.S. Department of Commerce, Coast and Geodetic Survey, 1951, UNITED STATES EARTHQUAKES, 1948: Serial No.746, by Murphy, L.M., and Ulrich F.P., 50p.

---, 1954, UNITED STATES EARTHQUAKES, 1952: Serial No.773, by Murphy, L.M., and Cloud W.K., 112p.

U. S. Department of Commerce, National Oceanic and Atmospheric Administration and U. S. Department of the Interior, Geological Survey, 1977, UNITED STATES EARTHQUAKES, 1975: Open-File Report 84-975, J.L. Coffman and C.W. Stover editors.

---, 1982, UNITED STATES EARTHQUAKES, 1980: C.W. STOVER and C.A. VON HAKE, editors

U.S. Geological Survey, 1983, UNITED STATES EARTHQUAKES 1983: Bulletin 1698, C.W. Stover editor.

Wahrhaftig, C. 1965, STEPPED TOPOGRAPHY OF THE SOUTHERN SIERRA NEVADA, CALIFORNIA: Geological Society of America Bulletin, Vol.76, pp.1165-1190.

Webb, R.W., 1946, GEOMORPHOLOGY OF THE MIDDLE KERN RIVER BASIN, SOUTHERN SIERRA NEVADA, CALIFORNIA: Geological Society of America Bulletin, Vol. 57, pp.355-382.

Weir, W.W., 1956, SOILS OF MADERA COUNTY, CALIFORNIA: Department of Soils and Plant Nutrition, University of California, Berkeley, 181p.

[illegible], Griscom, A., Jachens, R.C., Mooney, W.A., 1987, A TRANSECT ACROSS THE MESOZOIC ACCRETIONARY MARGIN OF CENTRAL CALIFORNIA: Geophysical Journal of the Royal Astronomical Society.

Wong, I.G. and Savage, W.U., 1983, DEEP INTRAPLATE SEISMICITY IN THE WESTERN SIERRA NEVADA, CENTRAL CALIFORNIA: Bulletin of the Seismological Society of America, Vol. 73, No. 3, pp.797-812.

Woodward-Clyde Consultants, 1975, MERCED AREA, IN PHASE II, REGIONAL SEISMICITY AND FAULT STUDY: Unpublished report submitted to Pacific Gas and Electric Company, San Francisco, California, Vol.5, 116p.

APPENDIX A

PHOTOGEOLOGIC INTERPRETATION AND IMAGERY ANALYSIS

HIDDEN AND BUCHANAN DAMS
NEAR MERCED, CALIFORNIA

Prepared for

U.S. Army Corps of Engineers
Sacramento District
DAC W05-87-R-0024

Project 437.05 | September 18, 1987

437A:05(69) | 9/18/87

PHOTOGEOLOGIC INTERPRETATION AND IMAGERY ANALYSIS

HIDDEN AND BUCHANAN DAMS

NEAR MERCED, CALIFORNIA

Prepared for

U.S. Army Corps of Engineers
Sacramento District

DAC W05-87-R-0024

by

Harlan Miller Tait Associates
San Francisco, California

Project No. 437.05

September 18, 1987

REGISTERED GEOLOGIST
ROBERT H. WRIGHT
No. 962
CERTIFIED
ENGINEERING
GEOLOGIST
STATE OF CALIFORNIA

Robert H. Wright
Principal Engineering Geologist 962

437A:05(68)

9/18/87

PHOTOGEOLOGIC INTERPRETATION AND IMAGERY ANALYSIS

HIDDEN AND BUCHANAN DAMS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

DATA SETS
(Original Only - Submitted Separately)

I. Imagery Photomosaics and Alternative Photos, Drainage and Lineament Overlays, and Lineament Map

1. SLAR photomosaic and lineament overlay

2. Skylab images (1:125,000) and lineament overlay

3. NASA Ames CIR photomosaic and lineament overlay, with alternative stereo images

4. Skylab image (1:125,000) and lineament overlay

5. NAPA panchromatic photomosaic and drainage and lineament overlay (rolled), with alternative stereo images

6. Lineament compilation map

II. 7.5 Minute Quadrangles showing Quaternary Deposits of Study Area

1. Preliminary geologic maps (7 Quadrangles) showing Quaternary deposits of the Merced area, eastern San Joaquin Valley, Merced County, California (Marchand, D. E., 1976a).

2. Preliminary geologic maps (8 Quadrangles) showing Quaternary deposits of the Madera area, eastern San Joaquin Valley, Madera and Fresno Counties, California (Marchand, D. E., 1976b).

3. Preliminary geologic maps (5 Quadrangles) showing Quaternary deposits of the Chowchilla area, eastern San Joaquin Valley, Madera and Merced Counties, California (Marchand, D. E., 1976c).

4. Preliminary geologic maps (8 Quadrangles) showing Quaternary deposits of the northern Merced area, eastern San Joaquin Valley, Merced and Stanislaus Counties, California (Marchand, D. E., 1976d).

5. Preliminary geologic maps (4 Quadrangles) showing Quaternary Deposits of the Daulton area, eastern San Joaquin Valley, Madera County, California (Marchand, D. E., 1976e).

6. Preliminary geologic maps (7 Quadrangles) showing Quaternary deposits of the southern Merced area, eastern San Joaquin Valley, Merced and Madera Counties, California (Marchand, D. E., 1976f).

Miller Tait

I. SUMMARY OF FINDINGS AND RECOMMENDATIONS

Based on the results of this study, we offer the following summary of findings and recommendations:

(1) The distribution and age control of Quaternary units in the study area is adequate to evaluate the origin of lineaments and the age of inferred faults;

(2) There are no known faults cutting Quaternary units in the study area;

(3) There are no major continuous lineaments associated with known or inferred faults in the study area;

(4) Lineaments in the study area reflect surface drainage features, geologic contacts, and bedrock structure including faults, joints and foliation;

(5) In order to further confirm the non-fault origin of lineaments and investigate the mapped inferred faults in the study area, we recommend further studies at six locations to include:

(a) Cleaning and logging of road cut exposures;

(b) Excavation and logging of backhoe trenches; and

(c) Review of logs of the Madera Canal, if available; and

(6) Assuming that the recommended further investigations do not reveal any evidence for faulting of Quaternary units, we conclude that there are no capable faults in the study area, and that the proper seismogenic source to use in evaluating the seismic stability of Hidden

and Buchanan Dams is that previously identified by the Corps, namely the Sierra Nevada Frontal Fault System (Owens Valley).

II. INTRODUCTION

This report presents the results of an imagery and photogeologic study of the area around Hidden and Buchanan Dams in the foothills of the Sierra Nevada east of Merced, California (Figure 1). The study was conducted during May through August of 1987 for the U.S. Army Corps of Engineers, Sacramento District, under Contract Number DACW05-87-R-0024. The study area includes portions of thirty-eight 7.5' and three 15' USGS Topographic Quadrangles and covers an area of approximately 38 by 51 miles (Figure 2).

A. Purpose

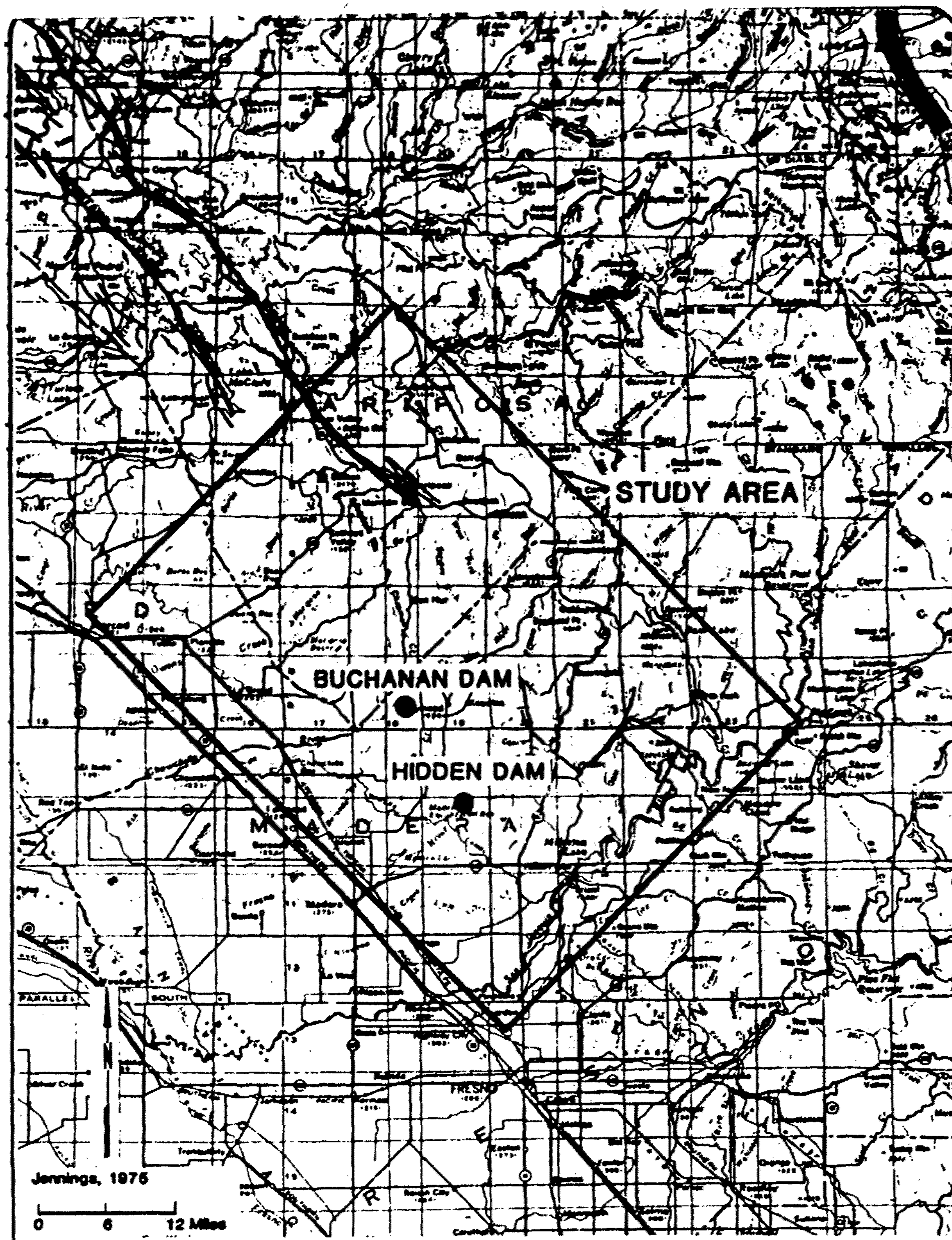
The purpose of the study was to provide an imagery and photogeologic analysis to identify and evaluate faults and lineaments in the area for inclusion in a broader overall study of fault capability assessment being conducted by the Corps.

B. Scope

The investigation included seven major tasks:

1. Task 1 - Literature Research

This task involved (1) the research, review and acquisition of available data pertaining to geology, previously mapped lineaments, and the basis for published faults, and (2) the identification of available imagery and the acquisition of representative pertinent imagery for analysis. Published maps and reports pertinent to the study area are listed in Section V,

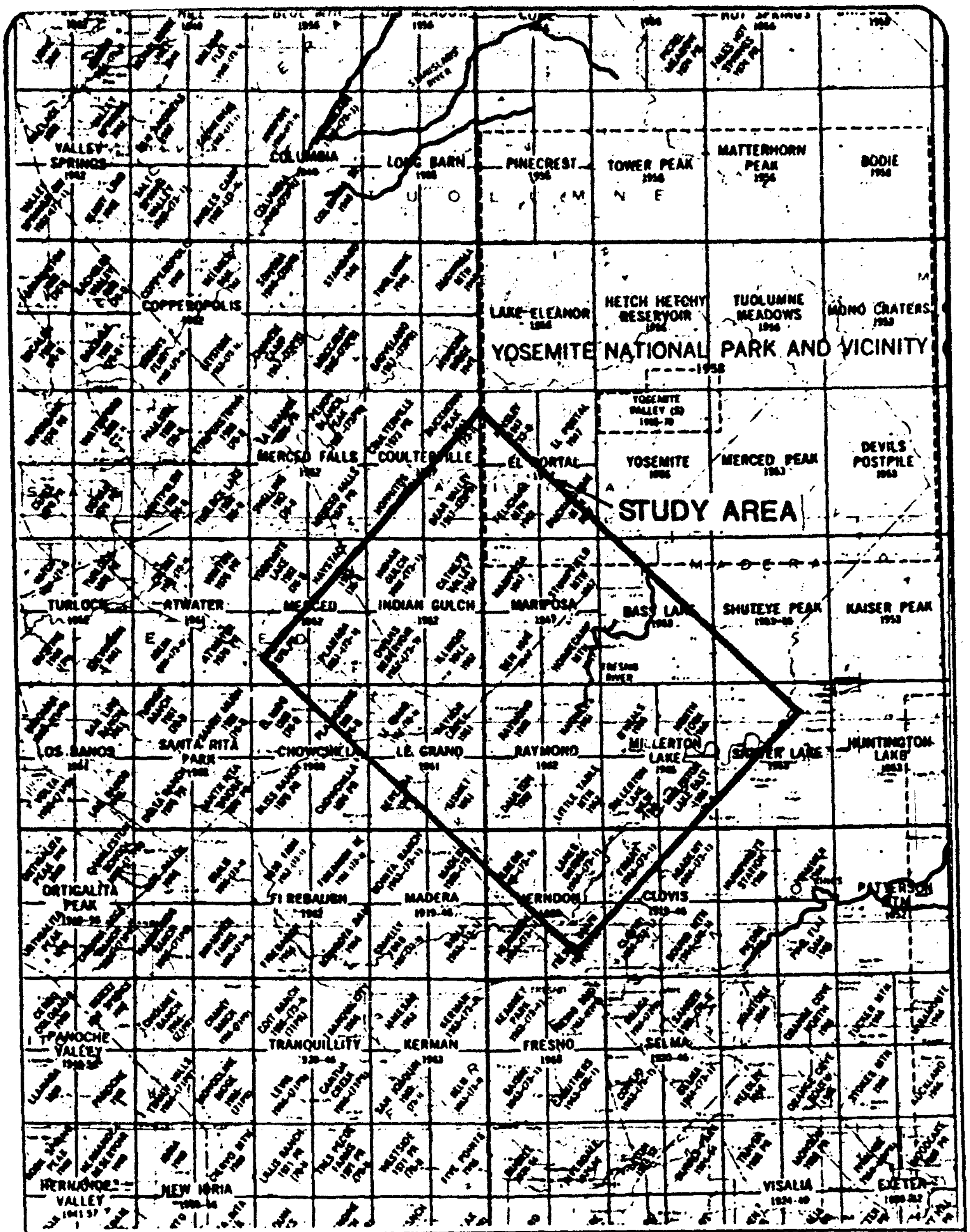


Harlan Miller Tait

LOCATION MAP OF STUDY AREA
HIDDEN AND BUCHANAN DAMS
Central California

FIGURE 1

Proj. No: 437.05 Date: 9/16/87 App'd by: R.N.W.



Harlan Miller Tait	INDEX MAP OF USGS QUADRANGLES HIDDEN AND BUCHANAN DAMS Central California	FIGURE 2
	Proj. No: 437.05 Date: 9/16/87 App'd by: R.W.W.	

References, and imagery acquired and analyzed is listed in Appendix A, Lineament Study, Table A-I.

2. Task 2 - Acquisition of Geophysical Data

This task involved the research, review and acquisition of available geophysical data, including gravity, aeromagnetic and deep seismic reflection profiles/interpretations, pertaining to the study area. Published maps and reports pertinent to the study area are listed in Section V, References.

3. Task 3 - Lineament Analysis

A variety of representative imagery covering the study area was obtained for analysis by purchase. This imagery was studied in detail by Photographic Interpretation Corporation (PIC) in order to map all lineaments in the study area. The imagery used, methods and results of this study are described in Appendix A of this report. Imagery, photomosaics and alternative photos, drainage and lineament overlays, and lineament compilation map are included as Data Set I and compiled on Plate 1 of this report. In addition, previous lineament studies were acquired, evaluated and compiled on Plate 1 of this report.

4. Task 4 - Areal and Quaternary Investigations

This task involved (1) the compilation of bedrock geology, (2) the compilation of Quaternary geology on a 1:100,000-scale topographic base map, and (3) field reconnaissance mapping to obtain supplemental data, "ground truth" interpretations and document-critical relationships, and to resolve conflicts. Copies of U.S. Geological Survey Open File

Reports showing Quaternary deposits of the study area on 7.5' quadrangles are included as Data Set II of this report.

5. Task 5 - Development of Map

This task involved (1) the assembly of a stable, reproducible topographic base map at a scale of 1:100,000 from enlargement of portions of 1:250,000-scale topographic maps, and (2) the compilation of bedrock and Quaternary geology, faults, and lineaments to produce the final Geologic and Lineament Map presented as Plate 1 of this report. Because of differences in scale and quality of base maps of the original sources, and uncertainty in transferring data, geologic contacts, faults and lineaments shown on Plate 1 should be considered to be approximately located within limits of error of about 0.25± mile.

Specific faults and lineaments discussed in this report are numbered consecutively within unique alpha-numeric grids, which approximate the boundaries of USGS 7.5' quadrangles, as shown on Plate 1. Letters define the grids in the north-south direction, and numbers define the grids in the east-west direction. For example, Lineament C4-1 is Lineament 1 in Grid C4 on Plate 1.

6. Task 6 - Evaluation of Locations for Trenching

This task involved the evaluation of locations for detailed mapping and trenching, and detailed logging based on the lineament analysis, and Quaternary geology recommended locations for further exploration presented and discussed in Section IV of this report.

7. Task 7 - Final Report

This task involved preparation of this report.

C. Performance

This investigation was carried out by Harlan Miller Tait Associates (HMTA), Roy J. Shlemon Associates (RJS), and Photographic Interpretation Corporation (PIC).

The investigation was directed by Dr. Robert H. Wright (HMTA), who was responsible for contract administration, liaison with the Sacramento District Office, and coordination of technical activities. Dr. Roy J. Shlemon (RJS) evaluated the distribution and age of Quaternary units using geomorphic and soil-stratigraphic techniques. Messrs. Vern Anderson and Roger Arend (PIC) performed the lineament analysis.

D. Acknowledgments

The study team wishes to acknowledge the valuable assistance of Messrs. Robert L. Treat, Thomas W. Fea, and Kim E. Jorgensen of the Corps' Sacramento District Office. We would also like to thank Mr. Carl Wentworth of the U.S. Geologic Survey, Menlo Park, for valuable discussions regarding ongoing research on the deep structure of the study area.

III. GEOLOGY OF THE STUDY AREA

A. Regional Geology and Tectonic Setting

Major units in the study region include Quaternary alluvium, Mesozoic igneous intrusive rocks, pre-Cretaceous metasedimentary, metavolcanic, and altered plutonic rocks (Plate 1).

The structural fabric of the bedrock units trends northwest-southeast parallel to the outcrop pattern of the Sierra Nevada and the Great Valley axis. This regional structure is related to the tectonic history of the region, the most significant elements of which include plate convergence between the Farallon and North American plates during the Cretaceous through Oligocene and the intrusion of batholithic masses with their volcanic equivalents into the accreted materials during the Mesozoic. By Late Cretaceous, the Sierra Nevada block was tilted toward the west with subsequent extensive erosion and corresponding deposition in the San Joaquin Valley to the west. Near the end of the Oligocene, subduction with east-west compression in the region ended, and gave way to transform movement with north-south compression along the San Andreas fault system. Since this time, the Sierra Nevada/Great Valley block has continued to tilt toward the west, but is otherwise a relatively stable block between the north-south compressive tectonic regime to the west and the east-west tensional tectonic regime of the Basin and Range province to the east. Seismicity in the study area is minor and the few located epicenters bear no relationship to known faults.

B. Geomorphology

1. Regional Overview

The study area encompasses two general geomorphic provinces; namely, the Sierra Nevada and foothills to the east, and the Great Valley to the west. Within each of these provinces, many individual geomorphic features exist, some of sufficient regional extent to warrant association with specific Quaternary geologic formations.

In general, most pre-Quaternary formations have now been dissected to form rolling to steep hills, not geomorphically distinctive. However, several major exceptions are apparent: specifically, northwest-trending, steep-sided valleys are common where differential erosion accentuates various splays of the Foothills fault zone, and high-standing, west-trending topographic inversions of topography give rise to the olivine-basalt of Table Mountain near Millerton Lake, and to ancient stream channels of the Merced River(?) now designated the China Hat (not present in study area) and North Merced Gravel (Plate 1).

Westward, relief decreases toward the Great Valley trough. This is geomorphically expressed mainly by the three major Quaternary depositional units of the eastern San Joaquin Valley, which generally give rise to moderately dissected topography (Turlock Lake Formation), to slightly dissected proximal fans, plains and fluvial terraces bordering major streams (Riverbank Formation), and to generally undissected fans and distributary channels (Modesto Formation).

2. Lineaments

Numerous lineaments were identified in the study area as part of

an independent lineament study presented as Appendix A of this report. In addition, a number of previous studies have mapped lineaments in the study area (PG&E, 1977; Marchand, 1976a-f; Marchand and Allwardt, 1978; Hodges, 1979). Lineaments from all available sources were compiled on Plate 1 of this report. As noted previously, specific lineaments discussed in this report are numbered consecutively within unique alpha-numeric grids shown on Plate 1.

a. Previous Studies

(1) PG&E (1977) - Numerous airphoto lineaments were mapped in the study area within a fairly uniform zone about four miles wide between the San Joaquin River and Chowchilla River during studies for the proposed Madera Nuclear Power Plant (PG&E, 1977, v. II, Figure VII A-10). The orientation of the majority of these lineaments is N35°-50°W, with a lateral spacing of 1,000 to 7,000 feet parallel to the Sierra Nevada foothill margin. Other orientations include N10°-25°W, N0°-10°E, N30°-60°E, and EW. The surface expression of these lineaments is primarily aligned gullies and swales in the Quaternary units, and small linear valleys and aligned notches and saddles in the bedrock.

Fourteen of the more prominent lineaments (D5-2, D6-2 and 3, E2 through 6, and G7-3 on Plate 1) were investigated by trenching. Although a few joints were encountered, no fault-related features were found, and no offset of soil horizons, lithologic contacts within the Turlock Lake Formation, or bedrock surfaces was observed.

(2) <u>Marchand (1976) and Marchand and Allwardt (1978)</u> - Marchand, in a series of publications showing Quaternary deposits in the study area region (1976a-f), mapped numerous lineaments from interpretation of 1:20,000-scale aerial photographs and U-2 photographs. These lineaments were later compiled on a single map (Marchand and Allwardt, 1978). The majority of the lineaments are in a zone which progressively decreases in width from about 12 miles just north of the San Joaquin River to about one mile east of Merced. The orientation of the majority of these lineaments is N20°-50°W, with a lateral spacing of about 1,000 to 8,000 feet parallel to the Sierra Nevada foothill margin. Other orientations include NS±, N20°-70°E and EW±. The surface expression of these lineaments is primary aligned gullies and swales in the Quaternary units, and small linear valleys and aligned notches and saddles in the bedrock. Inspection of both the topographic and field expression of many of the mapped lineaments indicates that extensive liberty was taken in deciding which linears to map, and in connecting short, discrete, and often offset, linears into one single longer lineament.

Marchand (1976a-f) and Marchand and Allwardt (1978) also mapped several short doubtful or inferred faults in the study area. Three of these inferred faults are recommended for further study (see Section IV, Recommended Exploration Locations).

(3) <u>Hodges (1979)</u> - A number of lineaments were mapped in the study area by Hodges (1979) from interpretation of

Landsat images and U-2 aircraft photographs. The orientation of the majority of these more regional lineaments is also northwest, parallel to the Sierra Nevada foothill margin. Other orientations include northeast and a curvilinear pattern within the bedrock of the Sierra Nevada north of Fresno.

b. <u>This Study</u> - A separate independent lineament study was conducted as part of the present study and is presented as Appendix A of this report. Lineaments were interpreted from a variety of imagery at several different scales and compiled on a 1:100,000-scale base map (Data Set I-6). As shown on this map, orientations of these predominately regional lineaments include a prominent northwest trend parallel to the Sierra Nevada foothill margin, in addition to strong NE and NS± trends, and a curvilinear pattern north of Fresno within the bedrock of the Sierra Nevada.

c. <u>Origin of Lineaments</u> - As noted previously, all lineaments from the sources discussed above were compiled on Plate 1 of this report. Closely paralleling and/or overlapping lineaments from two or more sources were combined on the assumption that they represented the same feature.

As shown on Plate 1, most of the mapped lineaments in the study area trend northwest, parallel to the regional northwest structural grain (foliation and joint set) of the Sierra Nevada. The majority of lineaments of this orientation occur southwest of the approximate boundary between bedrock outcrops and Tertiary and Quaternary units, and in a zone which progressively decreases in width from about 12

miles just north of the San Joaquin River to about one mile east of Merced. The general northwest decrease in the number of northwest-trending lineaments in the Quaternary units in the study area is mirrored by the general decrease in age of mapped Quaternary units at the surface from southeast to northwest.

The northeast-trending lineaments, particularly in the bedrock of the Sierra Nevada, are most likely related to the regional conjugate joint set. The great majority of these lineaments are northwest-trending secondary drainages, gullies, and swales which, together with the generally southwest-trending major drainages, form a trellis pattern.

The northeast-trending lineaments in the Tertiary and Quaternary units (e.g., C5-1, D6-4 and 5, E7-1 through 3, E7-4, and the swarm in the southwest corner of Grid F6 and northwest corner of Grid F7) reflect distributary channels within the Quaternary alluvial fan complexes.

The north-trending lineaments are probably related to a third, weaker joint set in the bedrock.

Some lineaments coincide with mapped bedrock faults, such as the Melones fault zone (D2-1), and the faults between Raymond and Auberry (F5-1 and 2, and H5 1 through 6), or are on projection of mapped faults (e.g., H6-1).

Several lineaments reflect linear reaches of major consequent drainages probably controlled by bedrock structure (joints). Examples include E6-7 projecting through Hidden Dam, F4-1 and 2, and H6-2.

Harlan Miller Tait

Other variously oriented lineaments are coincident with, or closely parallel, contacts between metamorphic and intrusive units (e.g., C3-2, C4-1, and E5-6 near Buchanan Dam). These lineaments most likely reflect the con^-^t, or paralleling structure, within the bedrock, which is clearly the case near Buchanan Dam. The trend of lineaments extending south from the Melones fault zone (Grids E3, E4, and E5) may be similarly related to contact/bedrock structure.

The trend of curvilinear lineaments (e.g., E5-1 through 4, F4-4 and 5) extending southwest and south through Grids F4, F5, E4, and E5 probably reflect intrusive structure related to igneous emplacement.

One lineament trend (C4-1), the County Line lineament - postulated fault, is coincident, in part, with a mid-1800's road (see Section D).

C. Geologic Units/Stratigraphy

1. Pre-Tertiary Bedrock Units

a. Undifferentiated Metamorphic Rocks - The undifferentiated metamorphic rocks in the study area compiled on Plate 1 (Mm) consist of Mesozoic sedimentary and volcanic eugeosynclinal rocks. These rocks were accreted to the North American plate and metamorphosed as at least two separate terranes, the Merced River and Foothills terranes, during Middle Jurassic and Late Jurassic respectively, of the Nevadan orogeny (Nokleberg, 1983). Geologic units within the undifferentiated metamorphic rocks unit include the Copper Hill, Gopher

Ridge, and Penon Blanco Volcanics, Salt Springs Slate, and Mariposa and Calaveras Formation.

b. Undifferentiated Intrusive Rocks - The undifferentiated igneous intrusive rocks in the study area compiled on Plate 1 (Mi) consist of Mesozoic plutonic rocks of the Sierra Nevada batholith intruded into the Mesozoic eugeosynclinal rocks during the Nevadan orogeny. These rocks range from ultramafic intrusives associated with major fault (suture) zones to granitic rocks which vary in lithology from gabbros and diorites to quartz diorites, quartz monzonite, granodiorite and granite.

2. Tertiary Units

a. Ione Formation (Eocene) - The oldest Cenozoic deposit in the study area is the middle Eocene age sandstone and kaolinitic clay of the Ione Formation (Ti on Plate 1). The formation, resting unconformably on bedrock, is characterized by white sandy clay near the base and layers of sandstone and quartz-rich conglomerate in the upper part. This material accumulated in a fluvial, deltaic and shoreline marine environment. The formation crops out in a discontinuous band a few miles wide adjacent to the belt of metamorphics along the east side of the Great Valley from Folsom in the north to Fresno in the south. The formation dips about 2 to 3 degrees and thickens to the west, and is progressively covered by younger sediments. The greatest exposure thickness of the Ione Formation is 95 feet; however, Davis and Hall (1959) estimate a maximum thickness of 200 feet based on width of outcrop and regional dip.

b. <u>Valley Springs Formation (Oligocene and Miocene)</u> - The Valley Springs Formation (Tv on Plate 1) is primarily composed of fluvially deposited rhyolite tuffs and tuffaceous sediments of late Oligocene to middle Miocene age (Dalrymple, 1964; Slemmons, 1966). It crops out extensively north and east of Merced. It is not mapped to the south, although Helley (1966) reported rhyolitic material in the soil at two locations near the head of the Chowchilla River alluvial fan where Arkley (1962a) had mapped soil types commonly associated with the Valley Springs Formation farther north.

c. <u>Auberry Formation (Miocene?)</u> - Reddish-stained cobble gravels of the Auberry Formation of Janda (1965· Ta on Plate 1) are exposed around the base of Little Table Mountain, a prominent butte at the head of the San Joaquin River alluvial fan, and in low hills nearby (Janda, 1966), and crop out in a discontinuous band extending to just north of the head of the Fresno River alluvial fan. These contain many locally derived metamorphic pebbles and cobbles. The gravels are differentiated from younger gravels by their dark staining, more advanced state of weathering, and greater induration. The gravels were deposited as early alluvial fan sediments of the San Joaquin River. They are Miocene in age based on a potassium-argon date of 9.5 ±0.3 million years obtained from an upper basalt member of the Auberry Formation exposed east of Millerton Lake (Dalrymple, 1963; Berggren, 1972).

d. <u>Mehrten Formation (Miocene and Pliocene)</u> - The Mehrten Formation (Tm on Plate 1) ranges in age from late Miocene to early

Pliocene (Axelrod, 1957; Slemmons, 1966). The formation is composed of a distinctive sequence of dark sandstone, conglomerate, and claystone. The material is largely andesitic, with less than 50 percent of other rock and mineral fragments. The type section of the Mehrten Formation is 45 miles north of Modesto in the northeast part of San Joaquin County (Piper and others, 1939). The Mehrten Formation crops out extensively north and east of Merced, and extends south as isolated patches to north of Madera.

e. Laguna Formation (Pliocene and/or Pleistocene) - The Laguna Formation (QTl on Plate 1) consists of an upper cobble gravel (China Hat Gravel member) and a lower member consisting of yellowish weakly-to moderately-indurated arkosic sand, silt, and minor gravel of Plio-Pleistocene age (Piper and others, 1939; Shlemon, 1971). The lower member of the formation crops out in a discontinuous band extending from just north of the head of the Chowchilla River alluvial fan to north and east of Merced.

f. North Merced Gravel (Pliocene and/or Pleistocene) - The North Merced Gravel (QTm on Plate 1) consists of locally derived pebbly and cobbly gravel deposited as pediment veneers. It crops out from north of the Merced River to south of the San Joaquin River (Hudson, 1960; Arkley, 1962a, 1962b; Janda, 1966; Helley, 1966). These late Pliocene to Pleistocene gravels are unconformable with both younger and older sediments.

3. Quaternary Units

a. General Stratigraphy and Age Relationships - Because of their importance to determine the possible presence and recency of fault movement, the distribution and approximate ages for Quaternary units have been particularly emphasized in this investigation. As shown on Plate 1, three general Quaternary geological formations are now well recognized on the east side of the San Joaquin Valley: Modesto (youngest), Riverbank, and Turlock Lake (Davis and Hall, 1959). These formations are best expressed as fluvial-fill terraces flanking major westward-flowing rivers, such as (for the Hidden and Buchanan area) the Merced and the San Joaquin, and to a lesser degree as terrace and alluvial fan sediments associated with the Chowchilla and Fresno rivers and Berenda Slough.

The Quaternary formations are generally distinguished from each other by their elevations above local stream base level, by degree of topographic dissection, and by relative soil profile development. The now-classic paper relating mapped soil series and geologic units is that of Arkley (1962a), who also first pointed out the probable relationship of Sierra Nevada glaciations to the formations (outwash) in eastern Merced County. These concepts were verified by Janda (1965), Janda and Croft (1967), and Shlemon (1967, 1972), who later extended the Quaternary soil stratigraphy to the Friant (Fresno) and the American River (Sacramento) areas, respectively.

More recent studies (Harden and Marchand, 1977; Helley, 1978; Marchand, 1976a-f, 1977; Marchand and Allwardt, 1978, 1981),

following the uranium-series dating of Hansen and Begg (1972), have attempted to quantify more specifically the age of the three Quaternary formations by use of uranium-trend and soil index measurements. These data studies confirmed that the Modesto, Riverbank, and Turlock Lake Formations, and their respective members, can be equated with regional changes of climate and sedimentation during the Quaternary. And these changes can be associated with the marine oxygen-isotope stage ($0^{18}/0^{16}$) chronology (Shackleton and Opdyke, 1973; see reviews in Shlemon, 1985).

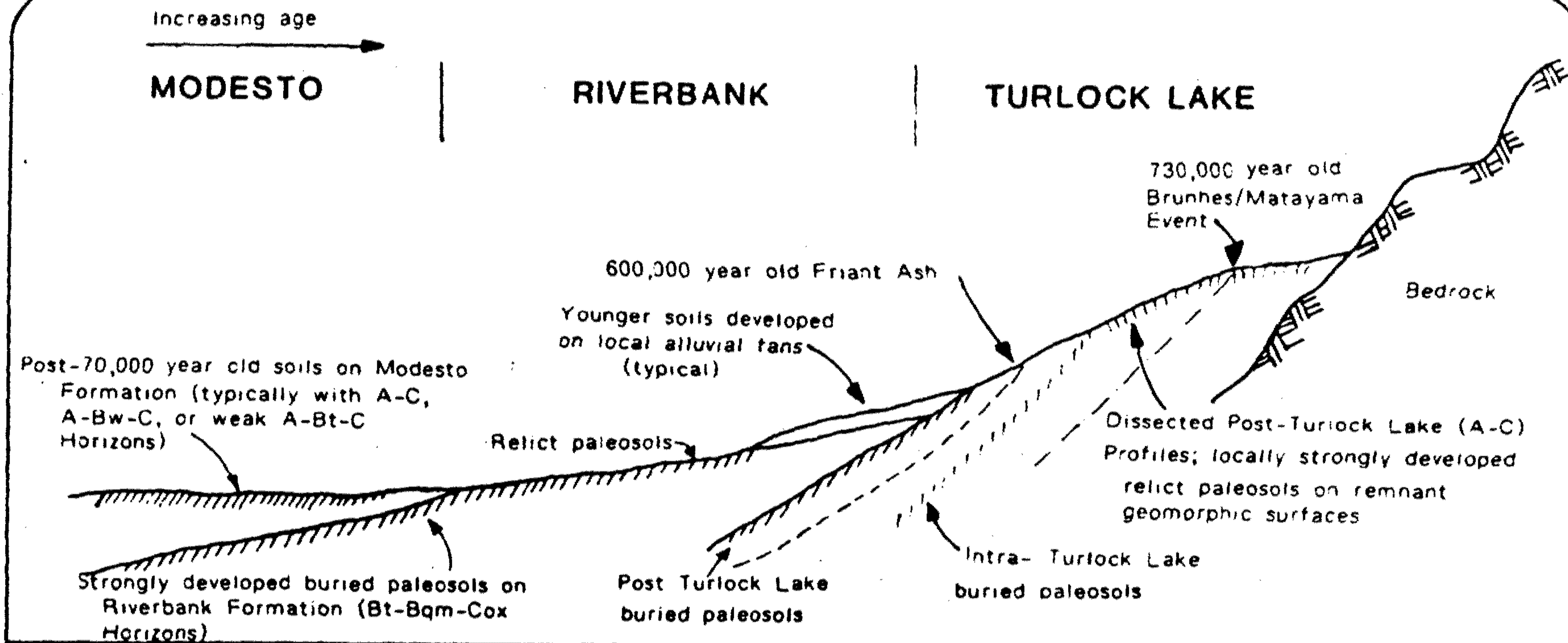
Published soil surveys cover most of the Hidden-Buchanan investigative area (Arkley, 1962b; Butler and Jones, 1974; Huntington, 1971; Ulrich and Stromberg, 1962). The soil-geomorphic relations established by Arkley (1962a) for Merced County hold true for most of the area, and were later used to construct Quaternary geological maps for the northeastern San Joaquin Valley (Marchand, 1976a-f; Marchand and Allwardt, 1978). Representative soil-geomorphic relations are as follows:

Geologic Formation (Quaternary and Tertiary)	Mapped Soil Series
Modesto	Delhi, Hanford, Dinuba, Greenfield
Riverbank	San Joaquin, Snelling, Ramona, Madera, Exeter
Turlock Lake	Montpellier, Whitney, Rocklin, Cometa
North Merced/China Hat	Redding, Corning
Laguna	Whitney, Rocklin
Mehrten	Pentz, Peters, Raynor
Valley Springs	Amador
Ione	Hornitos

Based on more recent investigations, the north Merced and China Hat "formations" of Arkley (1962a) are probably mainly channel deposits laid down by ancestral courses of the Merced River in Turlock Lake time. The Laguna Formation of Piper and others (1939) is, in part, stratigraphically equivalent to the lower Turlock Lake Formation in the Merced area (Arkley, 1962a), and to the informally designated "Fair Oaks formation" in the Sacramento area (Shlemon, 1967). The Tertiary-age Mehrten, Valley Springs, and Ione Formations all bear a wide variety of residual soils in addition to those mapped by Arkley, some of which may be relict paleosols (Singer, 1977).

The general age of the Quaternary formations can now be approximated by association with the isotope-stage chronology. As shown on Figure 3, the undeveloped to slightly-developed soils capping at least two well-documented members of the Modesto Formation identify sediments laid down during the last two major glaciations in the Sierra Nevada; namely, isotope stages 2 and 4, approximately 15,000 to 20,000 and 60,000 to 70,000 years ago, respectively. The post-Modesto soils, developed on granitic outwash, are usually characterized by undeveloped (A-C) profiles, or locally by slightly-developed subsoils (cambic and weak argillic horizons; A-Bw-C, and A-Bt-C).

In contrast, post-Riverbank Formation soils are strongly developed. These soils usually have well-discernible argillic B horizons with strong angular-blocky structure and moderately-thick clay films lining ped faces. In addition, iron-silica duripans (Bqm) characterize the San Joaquin and Madera soils, typical relict paleosols capping the



Approximate yrs Before Present (B.P.)	15,000-20,000	60,000-70,000	125,000-200,000	250,000-300,000	350,000-400,000	600,000 Friant Ash or "E" Corcoran Clay	730,000 → Brunhes/Matayama Magnetic Event
O^{18}/O^{16} Stages-Oxygen Isotope	2	4	6	8	10	12,14,16,18	20+

Harlan Miller Tait

QUATERNARY UNITS
AND AGE CORRELATIONS
HIDDEN AND BUCHANAN DAMS
Central California

Proj. No. 437.05 Date 9/16/87 App'd by: RKW

FIGURE 3

Riverbank Formation. Based on stratigraphic position and limited radiometric dating, the Riverbank Formation is generally associated with isotope stages 6 through 10, ranging in age from about 125,000 to 400,000 years before the present (B.P.; see Figure 3).

Where generally little dissected, the Turlock Lake Formation bears strongly developed soils, typified by the Montpellier Series (Arkley, 1962a). Usually, however, the formation is sufficiently eroded such that only less-developed soils cap these younger geomorphic surfaces. Nevertheless, based on stratigraphic position, and locally on the presence of at least one strongly developed buried paleosol and the approximately 600,000-year-old Friant ash (Janda and Croft, 1967; Shlemon, 1972, 1985), the formation is associated with isotope stages 12 through 20, and is therefore judged to range in age from about 400,000 to perhaps somewhat in excess of a million years (see Figure 3).

b. Description

(1) Turlock Lake Formation - The oldest of the regionally extensive Quaternary units in the eastern San Joaquin Valley, the Turlock Lake Formation, ranges in age from about 400,000 to probably in excess of a million years.

Regionally, the Turlock Lake Formation was probably laid down during several aggradational cycles, defined mainly by the presence of strongly developed buried paleosols (interglacial epochs of landscape stability) in the Merced and Sacramento areas (Arkley, 1962a; Shlemon, 1967). Textural and lithologic variation

within the formation is manifest by the presence of the K-Ardated, 600,000-year-old Friant Ash (pumice) traced by means of well logs westward into the south-central San Joaquin Valley (Janda and Croft, 1967), where it directly overlies the lacustrine Corcoran clay (Frink and Kuess, 1954). Additionally, a basal depositional unit bears the approximately 700,000-year-old Brunhes-Matayama magnetic reversal (Davis and others, 1977).

In the investigative area, the formation crops out mainly as low, dissected hills in Madera County, particularly between the Chowchilla River on the north and the San Joaquin River on the south (Plate 1).

Where exposed in road cuts and in a few stream cuts, the Turlock Lake Formation is typically comprised of interbedded granitic sand, silt, and local gravel. At least some silty units serve as stratigraphic markers, for in some road cuts they are traced as distinctive continuous beds for tens and locally for hundreds of feet.

(2) Riverbank Formation - The Riverbank Formation consists of alluvial fan deposits of granitic glacial outwash similar to the Turlock Lake Formation. It generally unconformably overlies western distal facies of the Turlock Lake Formation, and extends eastward through the Turlock Lake as depositional river terraces along entrenched sections of the rivers. The deposits vary from well sorted silt to gravel, with the fine-grained material characterizing the toes of fans and interdistributary areas, and the coarse-

grained material occurring in channels and close to the foothills at the heads of the fans (Janda and Croft, 1967).

In the study area, the Riverbank Formation is manifest as a slightly dissected plain forming the drainage divide bordering the Chowchilla River (Plate 1). Here, the Riverbank surface is generally only broken by local distributaries of the Chowchilla River bearing younger sand and silt of Modesto age.

Another extensive area of the Riverbank Formation occurs in the southern part of the study region, immediately north of the San Joaquin River. Although now increasingly modified by urbanization, old side-stream channels, tributary to the San Joaquin River, still visibly dissect the surface in this area. As shown on Plate 1, many of these channels correspond to photographic lineaments.

Regionally, three members of the Riverbank Formation are recognized, based mainly on geomorphic expression on soil profile development, and on the presence of buried paleosols and channel deposits (Huntington, 1971; Marchand and Allwardt, 1981; Shlemon, 1972). The formation has been approximately dated by both radiometric and relative dating techniques as ranging from about 100,000 to somewhat in excess of 400,000 years (Hansen and Begg, 1970; Marchand and Allwardt, 1981).

(3) Modesto Formation/Alluvium/Dredge Tailings - The Modesto Formation, from its type locality on the Tuolumne River (Davis and Hall, 1959), has now been mapped throughout much of

the eastern San Joaquin and Sacramento Valleys (see, for example, Arkley, 1962a; Huntington, 1971; Janda and Croft, 1967; Marchand and Allwardt, 1978, 1981; Shlemon, 1967). The formation, comparable to the older Riverbank and Turlock Lake deposits, is mainly granitic in lithology laid down primarily as fans, terraces and channels.

Two sequences of Modesto age are generally recognized: an older unit preserved principally as fluvial terraces a few to several feet above present flood plains, and a younger unit manifested mainly by wide-spread alluvial fans, best expressed west of the study area. The two units are often more clearly separated by capping soils: the older (higher) surfaces usually bearing slightly developed profiles with weak argillic horizons; the younger surface normally typified by lack of subsoil development. Based on soil profiles and limited radiocarbon dates, the Modesto Formation was likely laid down in the interval between about 10,000 and 80,000 years ago, mainly during isotope stages 2 and 4 (Sierra Nevada, Tioga, and Tahoe glaciations), respectively (see Figure 3).

For purposes of this investigation and owing to map scale, Holocene flood plain and related disturbed terrain (namely dredge tailings, dam embankments, and related earthworks) are not separated from the Modesto Formation on Plate 1.

In the study area, these combined deposits are present in three general locations: (1) to the north near the Merced-Madera County line; (2) a central region of flood plain and dis-

tributary deposits associated with the Chowchilla and Fresno Rivers and with Berenda Slough; and (3) to the south bordering the San Joaquin River (Plate 1). Most Modesto-age deposits are intensively farmed; hence, most of the terrain has been levelled and brought into irrigated agriculture. Accordingly, few natural or man-made exposures are present for inspection. However, adjacent Riverbank and Turlock Lake sediments are abundant, providing markers useful to trench and, thereby, determine the origin of photographic lineaments.

D. Structure

1. Faults

a. Regional Overview - The major structure of interest in the study area from a neotectonic standpoint is the southern extension of the Foothills fault system (Duffield and Sharp, 1975; Jennings, 1975; Bryant, 1983). To some degree, concerns about possible late-Quaternary activity on this system sten investigations for the Auburn and New Melones damsites and us nuclear power plant siting studies in the region. More recent trenching and soil-stratigraphic investigations east of Sacramento, north of the study area (Tierra Engineering Consultants, 1983) at Folsom Dam showed that at least some of the faults in the Foothills fault system are old, certainly not active for at least the last 35,000 to 40,000 years, and probably well before that time. Recent trenching of lineaments associated with the Kings-Kaweah suture, a possible southern extension of the Foothills fault system (U.S. Army Corps of Engineers, 1979), showed no dis-

Harlan Miller Tait

placement of post-Riverbank Formation soils (approximately 100,000 years old), and locally a strongly developed buried paleosol (about 600,000 years old) within the Turlock Lake Formation (Shlemon, 1986).

b. Faults in Study Area - As noted previously, the faults and inferred faults in the study area discussed below are keyed to Plate 1 by a grid and number system for ease of location.

(1) St. Mary's Mine Fault - Lineament - The St. Mary's Mine fault (C3-1), located near the northwestern boundary of the study area, was discovered during siting investigations for the proposed Merced nuclear power plant (PG&E, 1977). Mine excavations in the St. Mary's Mine area in the SE¼, SE¼, Section 29, T5S, R16E, Indian Gulch 7.5' Quadrangle, exposed several areas of fault gouge and a fault plane. Slickensides on the fault plane are oriented almost directly down dip (45 degrees north), but the sense of displacement is not known. An associated lineament, the St. Mary's lineament (C3-2), trends southeast along the southwest margin of the Guadalupe igneous complex as an alignment of springs, vegetation, mines, and topographic lows, and is approximately coincident with a long northwest-southeast trending stringer of intrusive rock south of Highway 140. It is one of the most prominent lineaments in the northern part of the study area, and probably is a fault along most of its length. The fault and lineament are within a postulated ductile shear zone inferred to mark the boundary between belts of rocks amalgamated along the southern continuation of the Bear Mountains fault zone during

and after Nevadan deformation (Paterson and others, 1987). The fault is considered non-capable and displacement on this fault is probably Mesozoic, although there are no known Cenozoic deposits overlying the fault.

(2) County Line Lineament - Postulated Fault - A fault has been postulated as the origin for at least a portion of a northwest-southeast trending lineament parallel to and near the Merced-Mariposa County line, north and south of Highway 140 (PG&E, 1977; Marchand and Allwardt, 1978; Marchand, 1976a). However, field inspection shows that much of this lineament appears to be due to cultural features associated with a mid-1800's road located along the present county line. Nevertheless, because Marchand and Allwardt (1978) suggested that the Ione Formation may be offset, west side down, as much as 80m along this postulated fault north of Highway 140, this feature is recommended for further study at a location just south of Bear Creek (see Section IV, Recommended Exploration Locations).

(3) Page and LeBlanc Lineament - Postulated Fault / Clovis Inferred Fault - A fault has been postulated for a lineament (G7-1) located north of Fresno and south of the San Joaquin River, identified by Page and LeBlanc (1969). It is shown as a dotted pre-Quaternary fault on the Fault Map of California (Jennings, 1975), and has also been called the Clovis fault. Evidence of faulting (Page, personal communication, 1974, in PG&E, 1977) includes possible bedrock offset inferred from drilling logs and a

lineament on aerial photographs. However, there are no offsets of Quaternary alluvium or ground water anomalies associated with this lineament. Fugro (1974) examined the lineament in the field and a boring was drilled on each side of its topographic expression. Interpretation of the boring data led them to conclude that there was no major bedrock offset along the lineament. Further investigation of Tertiary rocks (Ione Formation) on Little Table Mountain demonstrated the continuity of these beds across the projected strike of the lineament and, therefore, the absence of fault offset. The Page and LeBlanc lineament is thus considered one of the northwest-southeast trending lineaments in the area, and unrelated to faulting.

(4) Bedrock Fault at Hidden Dam - A small bedrock fault, approximately 300 feet long, was mapped during foundation excavations for Hidden Dam (Robert L. Treat, U.S. Army Corps of Engineers, personal communication, 1974, in PG&E, 1977. The fault cuts intrusive rock of Mesozoic age. This minor feature terminated within the exposed length of the excavation and hence is not considered capable.

(5) Bedrock Faults between Raymond and Auberry - Several bedrock faults (E5-1 and 2; H5-1 through 6), up to a maximum of about eight miles long, are mapped in the area northeast of Millerton Lake, between Raymond and Auberry (Jennings, 1973). Field investigation of these structures during siting investigations for the proposed Merced nuclear power plant (PG&E, 1977) re-

vealed no positive evidence of faulting. The "faults" occur in granitic and metamorphic rocks of Mesozoic age. One of them is partly overlain by unfaulted basalt of the Miocene age Auberry Formation (Strand, 1967) and hence these "faults" are not considered capable.

(6) Other Faults

(a) Berenda Creek Inferred Fault - Marchand (1976c) mapped a short north-south trending fault (D6-1), herein informally termed the Berenda Creek fault, in a road cut on the north side of Avenue 24 just northwest of Berenda Creek in the central portion of the st:.'y area. No evidence of faulting of the exposed Riverbank Formation sediments was observed during field reconnaissance, and the inferred fault is not associated with a lineament. However, the site is recommended for further study (see Section IV, Recommended Exploration Locations).

(b) Avenue 15 Inferred Fault - Marchand (1976b) mapped a short northwest-southeast trending fault (E7-1), herein informally termed the Avenue 15 fault, in a road cut on the north side of Avenue 15 in the southern part of the study area. The inferred fault is expressed as an apparent vertical offset of stratification in the Turlcck Lake Formation (minimum about 400,000 years old). The site is recommended for further study (see Section IV, Recommended Exploration Locations).

(c) Millerton Lake Lineament - Postulated Fault - A relatively short, northwest-southeast-trending lineament (G7-2) mapped by Marchand (1976f) just east of Millerton Lake on the San Joaquin River, is inferred by Marchand and Allwardt (1978) to possibly offset, down to the west, the Miocene age Auberry Formation basalt of Table Mountain just east of Friant. This lineament was not field checked during this study. If it is a fault, it is a minor feature and is not considered capable.

(7) Foothills Fault System - The Foothills fault system is located within and generally parallel to the structural fabric of the metamorphic belt of the western Sierra Nevada, and extends for several hundred miles from Lake Almanor southeast into the northeastern part of the study area (Jennings, 1975). Clark (1960; 1964) recognized two major structural zones within the system: the Bear Mountain fault zone and the Melones fault zone. Both zones are now generally considered to reflect amalgamation or suturing of probable oceanic island arc material onto the North American plate during the Late Jurassic Nevadan orogeny.

The Melones fault zone (D2-1 on Plate 1) is mapped as extending to, but not penetrating, the Mesozoic igneous rocks just southeast of Mariposa (Jennings, 1975). Bateman and others (1983) infer that the Melones fault zone had swung southwesterly to pass between the Adobe Hill and Tick-Tack-Toe roof pendants southeast of Hidden Dam, prior to intrusion of the igneous rocks.

Nokleberg (1983), on the other hand, suggests the Melones fault zone continued southeasterly, passing through what is now the Oakhurst roof pendent, before swinging southwesterly south of the San Joaquin River and disappearing beneath the Cenozoic cover of the Great Valley. Investigations south of the study area between the Kings and Tule Rivers have identified a "shear zone" within the metamorphic belt termed the Kings-Kaweah suture (Saleeby, 1975; Schweickert and others, 1977). The Kings-Kaweah suture has been investigated by the U.S. Army Corps of Engineers (1979), and is currently being further investigated by the Corps as part of an evaluation of Success and Terminus Dams. Conclusions of the Technical Review Board, based on the preliminary results of the latter study (Harlan Miller Tait, 1987; O'Neill, 1987) are that the "shear zone" (Kings-Kaweah Suture) may be the southern extension of the Melones fault zone in that the "shear zone" represents the equivalent locus of amalgamation in the Success/Terminus area. However, the continuity of the "shear zone" is disrupted by Mesozoic intrusive rocks (Harlan Miller Tait, 1987) and covered by unfaulted Quaternary units probably older than about 300,000 years (Shlemon, 1986). The southern portion of the Melones fault zone and its probable southeastern extension as the Kings-Kaweah suture are thus considered non-capable.

The Bear Mountain fault zone (C2-1) is generally mapped as extending to the vicinity of Schultz Mountain (Rogers, 1966; Nokleberg, 1983). A recent study by Paterson and others

(1987) proposes that the Bear Mountain fault zone continues southeasterly into Grid D4 (Plate 1) along the southwestern margin of the Guadalupe igneous complex (Schultz Mountain), as a shear zone separating distinct belts of rock within the Foothills terrane. The St. Mary's Mine fault (C3-1) and associated lineament (C3-2) discussed previously lie within this zone. Paterson and others (1987) characterize the zone as steeply dipping with predominately reverse, east over west, shear movement with a small left-lateral component. They interpret the zone as the boundary between belts of rocks amalgamated to North America during and after Nevadan (extending into the Cretaceous) deformation. Although there is no Cenozoic cover in the area, the zone appears to be breached by a small Mesozoic igneous pluton northeast of Mariposa Creek Dam (Grid D4 on Plate 1), and thus the southern portion of the Bear Mountain fault zone is considered non-capable.

c. Other Faults in Region

(1) Arkley's Postulated Fault Zone - North of Merced near Turlock Lake, northwest of the study area, Arkley (1962) postulated a "fault zone" trending northwest-southeast, approximately coincident with a zone of northwest-southeast-trending lineaments. This "fault zone" has never been placed on a geologic map. No evidence of faulting associated with this group of lineaments was found during siting investigations for the proposed Madera nuclear power plant (PG&E, 1977).

(2) Stoney Creek Fault - A normal fault cutting the Valley Springs Formation was discovered in an outcrop on the north bank of Stoney Creek in the SE¼, NE¼, Section 17, T5S, R15E, Merced Falls 7.5' Quadrangle, north of the study area, during siting investigation for the Merced nuclear power plant (PG&E, 1977). The fault strikes north 25 degrees east, dips 57 degrees west, and has 15 to 18 inches of stratigraphic separation with the west side down. The fault was trenched and shown to be overlain by unfaulted Riverbank Formation (100,000 to in excess of 400,000 years). Further detailed investigation of scattered outcrops to the south revealed no readily identifiable sign of the fault. The fault is therefore a minor feature and is not considered capable.

(3) Merced Falls Faults - One major fault and several associated minor faults were found during foundation excavations for McSwain Dam in Sections 3, 10, and 11, T5S, R15E, of the Merced Falls 7.5' Quadrangle, north of the study area (Woodward-Clyde Consultants, 1975). The major fault was a zone up to 110 feet wide and one mile long marked by massive, near-vertical quartz outcrops. This fault displaces the Mesozoic age Gopher Ridge Formation and the Merced Falls Slate. However, deposits of Pliocene and/or Pleistocene North Merced Gravel and of the Eocene Ione Formation apparently cross the trend of the fault zone approximately one-half to one mile to the northwest of the dam, and thus the fault is not considered capable.

Harlan Miller Tait

(4) Merced River Gorge Faults - Two short faults displace a small granitic stock that intrudes the Mesozoic Gopher Ridge Formation one mile upstream from McSwain Dam in Section 35, T4S, R15E of the Merced Falls 7.5' Quadrangle, north of the study area (Woodward-Clyde Consultants, 1975). The fault is not considered capable.

(5) Big Bend Fault - The northeast-southwest trending, north side down, Big Bend fault was discovered during siting investigations for the proposed Merced nuclear power plant (PG&E, 1977) in a large bend in a tributary to Dry Creek, in the SW¼, Section 15, T4S, R14E of the Snelling 7.5' Quadrangle, northwest of the study area. The presence of a fault was revealed by an apparent 10- to 15-foot stratigraphic separation of a tuff bed in the Oligocene and Miocene Valley Springs Formation. Overlying deposits of Pliocene and/or Pleistocene North Merced Gravel, or possibly the Pleistocene Turlock Lake Formation, are not displaced, and the fault is not considered to be capable.

(6) Hayward Creek Fault - The Hayward Creek fault is an east-west trending fault located in Sections 32, 33, 34, 35 and 36, T3S, R14E, northwest of the study area (PG&E, 1977). The fault forms the contact for two miles between the Mesozoic age Peaslee Creek Formation and Merced Falls Slate, and projects beneath unfaulted Eocene Ione Formation (Rogers, 1966). It is not considered capable.

(7) <u>Gill Ranch Gas Field Faults</u> - Several concealed faults are identified from subsurface well data (Loken, 1959) in the Gill Ranch gas field, southwest of the study area. The basement is offset 400 feet on the main fault, with diminishing offset to 75 feet in the overlying Mesozoic and Tertiary units (Bayoumi, 1961). Because no Quaternary offset has been reported for these faults, they are not considered capable.

(8) <u>China Hat Fault - Lineament</u> - The northwest-trending China Hat fault and associated northwest and north-trending lineaments were mapped by Marchand and Allwardt (1978) about six to nine miles north-northwest of Merced northwest of the study area. The fault is exposed in the access road to the Merced County landfill, just east of Oakdale Road. The fault breaks the Laguna Formation into several rotated blocks and the lineaments pass through the overlying Turlock Lake and Riverbank Formations. Marchand and Allwardt (1978) report about 13 feet of post-North Merced (Pliocene and/or Pleistocene) offset, down to the west, with no evidence of late Quaternary displacement, and the feature is considered non-capable.

(9) <u>Canal Creek Lineament - Inferred Fault</u> - a northwest-trending lineament is expressed on Quaternary units some six to eleven miles north-northwest of Merced, northwest of the study area. The lineament is parallel to and about 1.5 miles west of the China Hat fault lineament and is inferred by Marchand and Allwardt (1978) to possibly truncate the upper surface of the

China Hat member of the Laguna Formation (Pliocene and/or Pleistocene), down to the west, but no displacement is verified.

2. Bedrock Structures

a. Folds - Northwest-trending isoclinal folds are present in the Mesozoic metamorphic rocks (Mariposa Formation), but are not mapped on Plate 1. No folds occur in the Cenozoic rocks in the study area.

b. Regional Dip - The buried, relatively flat bedrock surface on the metamorphic and intrusive basement rocks of the Sierra Nevada, underlying the Cenozoic sedimentary cover, slopes westward approximately 4 to 5 degrees (Smith, 1964). Progressive westward tilting of the Sierra Nevada block during late Tertiary and Quaternary time (Bateman and Wahrhaftig, 1966) has resulted in a gentle, southwesterly dip in the Cenozoic strata which is greatest in the oldest, most deeply buried strata and decreases upward. Dips decrease from approximately 2 to 3 degrees in the Eocene Ione Formation to approximately 0.2-degree in the Turlock Lake Formation (Janda, 1966), to approximately 0.05-degree in the Modesto Formation and modern drainages/alluvial fans (Janda, 1966).

c. Foliation - A pervasive regional northwest-southeast foliation parallel to the Sierra Nevada foothill margin is present in the Mesozoic metamorphic rocks in the study area.

d. Joints - A prominent regional joint system occurs in the study area. The joints are more prominent in the unfoliated intrusive rocks and in the Eocene Ione Formation, although they also occur in rocks of the metamorphic belt. The primary joint set strikes N10°-

55°W and dips 60°-80NE. A conjugate set strikes N20°-55°E and dips 60°-80°NW. A minor third set of joints strike NS± and dip east.

3. Summary of Geophysical Data

The metamorphic rocks of the Sierra Nevada foothills, as well as the Franciscan assemblage in the Coast Ranges, have long been considered to be type examples of subduction accretion, formed by the interaction of oceanic and island arc/continental basement rocks along the Pacific margin of Mesozoic North America.

A regional unconformity on the Jurassic metamorphic rocks of the foothills dips gently westward from the foothills beneath the Cretaceous and Cenozoic strata of the Great Valley. The Sierra Nevada batholith of Mesozoic age abuts these foothills to the east.

Available aeromagnetic data for a large part of central California define a number of subparallel, northwest-trending anomalies. These anomalies are believed to be largely caused by serpentinized ultramafic rock similar to rocks outcropping in the foothills marking former subduction or obduction zones. In contrast, areas underlain by granitic rock, such as much of the Sierra Nevada, are characterized by non-linear, isolated aeromagnetic highs and lows.

Oliver and Hanna (1970) have interpreted aeromagnetic anomalies associated with the serpentinite body bounded by the Melones fault zone, north of the site, to indicate a steep dip eastward. The magnetic anomalies associated with the Melones and Bear Mountain fault zones clearly terminate in the southern Sierra foothills, south of the surface trace, where the magnetic pattern becomes one of scattered, rather equidimensional, moderate

highs and associated lows that typify the entire batholithic terrane to the south and east. Although these structures are exposed on the surface as steeply east-dipping, Moores and Day (1984; see also Paterson and others, 1987) suggest that the foothill metamorphic rocks were emplaced along eastward-directed, westward-dipping thrusts during the Nevadan orogeny. Blake and others (1977) interpret the aeromagnetic anomalies as showing the mafic oceanic layer as obducting or overriding itself beneath the eastern margin of the Great Valley.

Wentworth and others (in press) and Zoback and Wentworth (1986) interpreted data from the seismic reflection profiles at approximately 37.25 degrees latitude, between Merced and Chowchilla. These papers report the presence of major mid-crustal reflectors dipping approximately 30 degrees west. The authors extrapolate these reflectors to the surface at the latitude of the seismic line in the area where southeastern extensions of the Bear Mountain and Melones fault zones would project. Although this geometry is compatible with proposals for eastward-directed obduction of oceanic (mafic) rocks onto the continental margins, it is not clear how this westward dip may relate to the steeply eastward-dipping structures exposed in the Sierra Nevada foothills. Zoback and Wentworth (1986) suggest that a similar geometry in the Coast Range Thrust may be explained by a recumbent geologic structure.

Other geophysical investigations near the site area include a micro-earthquake monitoring program conducted from 1976 to 1979 (Wong and Savage, 1983). Two areas of clustered earthquake swarms, consistent with historical seismicity, were recognized in an area 15km south of the

town of Madera and an area 15km south of Mariposa. No association of the seismicity with faults or other geologic structures expressed at the surface was apparent. Focal mechanisms of these predominately deep crustal earthquakes are interpreted as representing a transition between a region of primarily shear deformation along the San Andreas fault zone and extensional tectonics of the Basin and Range province.

IV. RECOMMENDED EXPLORATION LOCATIONS

A. Selection Criteria

Several criteria were used to select locations for detailed mapping and trenching and detailed logging. These criteria include:

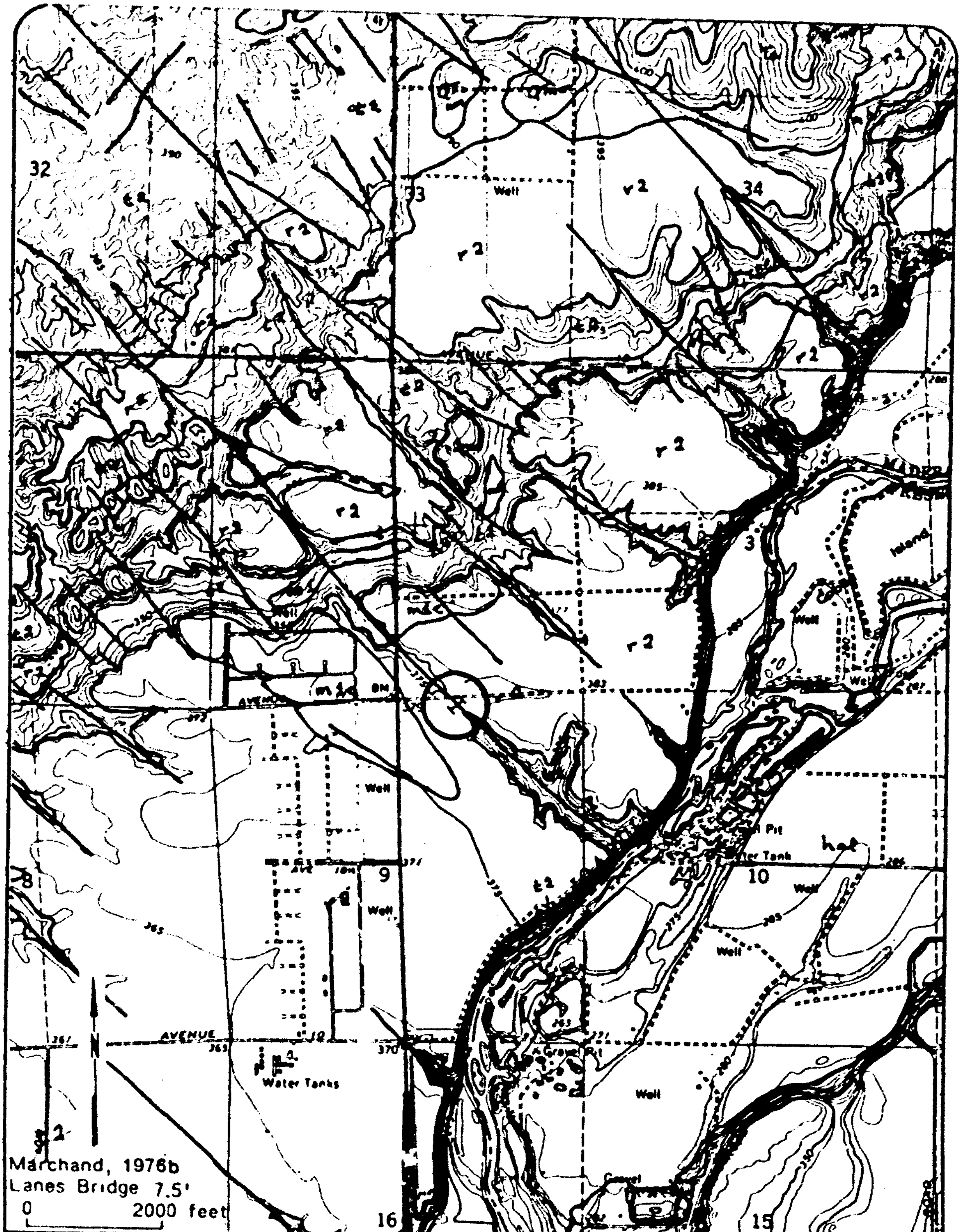
1. Published (mapped) known or inferred faults in the study area;
2. Lineament expression, including length and strength within a reasonably defined swarm or association;
3. Distribution of lineaments throughout the study area;
4. Known approximate age of sediments based on previous mapping and confirmed by field inspection;
5. Presence of geomorphic surfaces and/or soil profiles conducive to verify age of sediments; and
6. Relative ease of access.

Based on the above criteria, six exploration sites were identified and are recommended for further study as discussed below.

B. Recommended Exploration Locations

1. Exploration Site 1

Site 1 is considered high priority and is recommended for trenching and detailed logging. It is located in the NE¼ of Section 9, T12S, R20E on the Lanes Bridge, California 7.5' Quadrangle in an unplowed/undisturbed field on the south side of the easterly extension (private?) of Avenue 11, about 900 feet east of the intersection with Highway 41 (Figure 4).



Harlan Miller Tait

RECOMMENDED EXPLORATION SITE 1
HIDDEN AND BUCHANAN DAMS
Central California

FIGURE 4

Proj. No: 437.05 Date 9/16/87 App'd by: RN.W

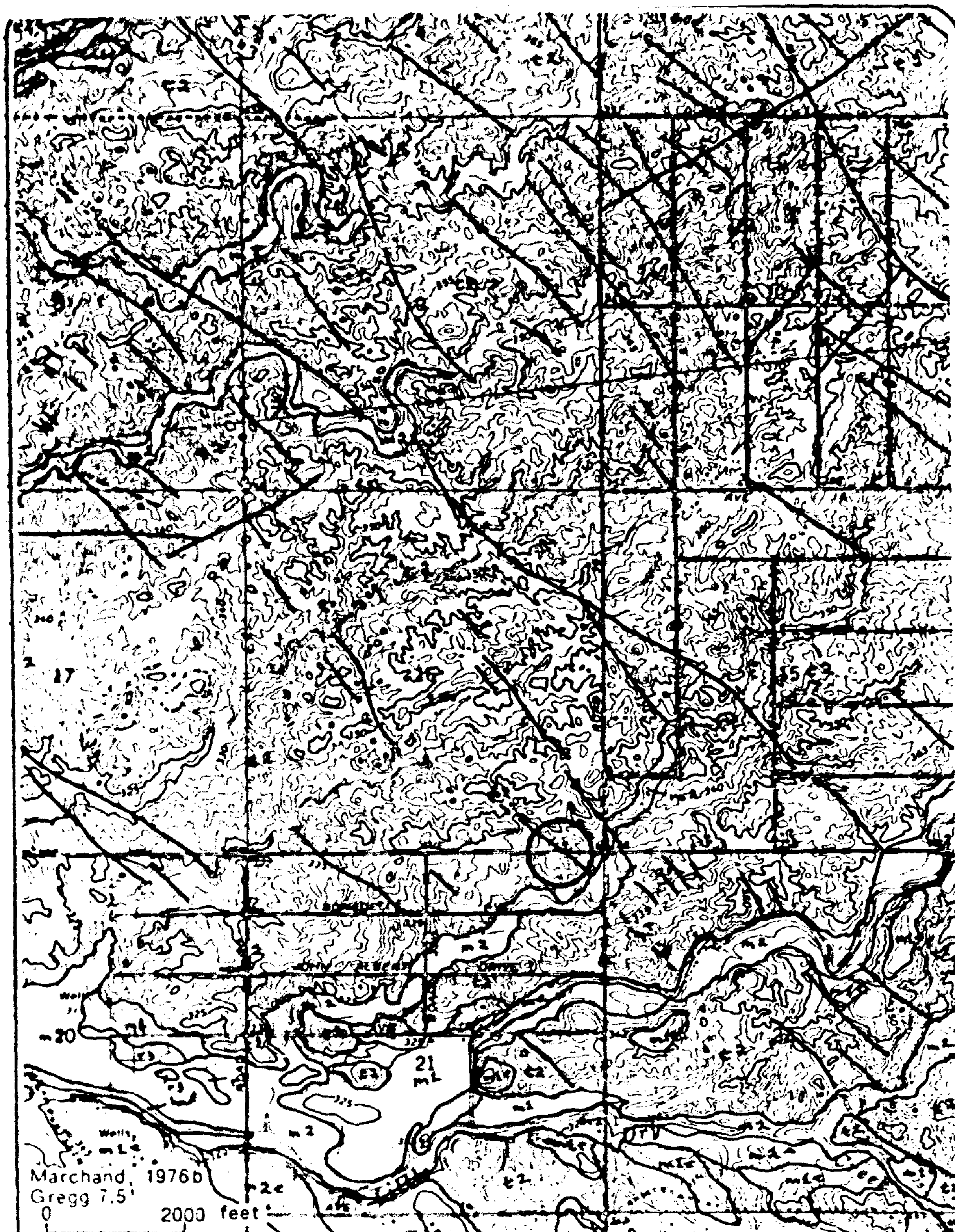
The site is located to investigate one of the most prominent of the "swarm" of northwest-trending lineaments mapped on the north side of the San Joaquin River (Marchand, 1976b), and the results will be useful in explaining the origin of similar northwest-trending lineaments in the area.

The trench should be oriented northeast-southwest perpendicular to the lineament (F7-1, Plate 1), readily identifiable on the ground as a linear swale/drainage across a well displayed geomorphic surface, and placed on a low drainage divide about 50 to 75 feet south of the road. The trench will encounter late Riverbank Formation sediments laid down by the San Joaquin River at a relatively moderate depth (five to ten feet deep), and should be long enough, about 200 to 250 feet, to expose the soil profile underlying the geomorphic surface. The trench is likely to expose a well developed duripan (silcrete) of the San Joaquin series (minimum about 100,000 years old).

2. Exploration Site 2

Site 2 is recommended for trenching and detailed logging, and for cleaning and logging of a road-cut exposure. The site is located in the SE¼ of Section 16, T11S, R19E on the Gregg, California 7.5' Quadrangle on the north side of Avenue 15, about 600 feet west of the intersection with Road 36 (Figure 5). The site is located to investigate one of the short northwest-trending inferred faults in the study area (Marchand, 1976b), and the results can document or refute the presence of the inferred fault mapped at this location, and be useful in explaining the origin of similar northwest-trending lineaments in the area.

The inferred fault (E7-1, Plate 1) is expressed as an apparent



Harlan Miller Tait

RECOMMENDED EXPLORATION SITE 2
HIDDEN AND BUCHANAN DAMS
Central, California

FIGURE 5

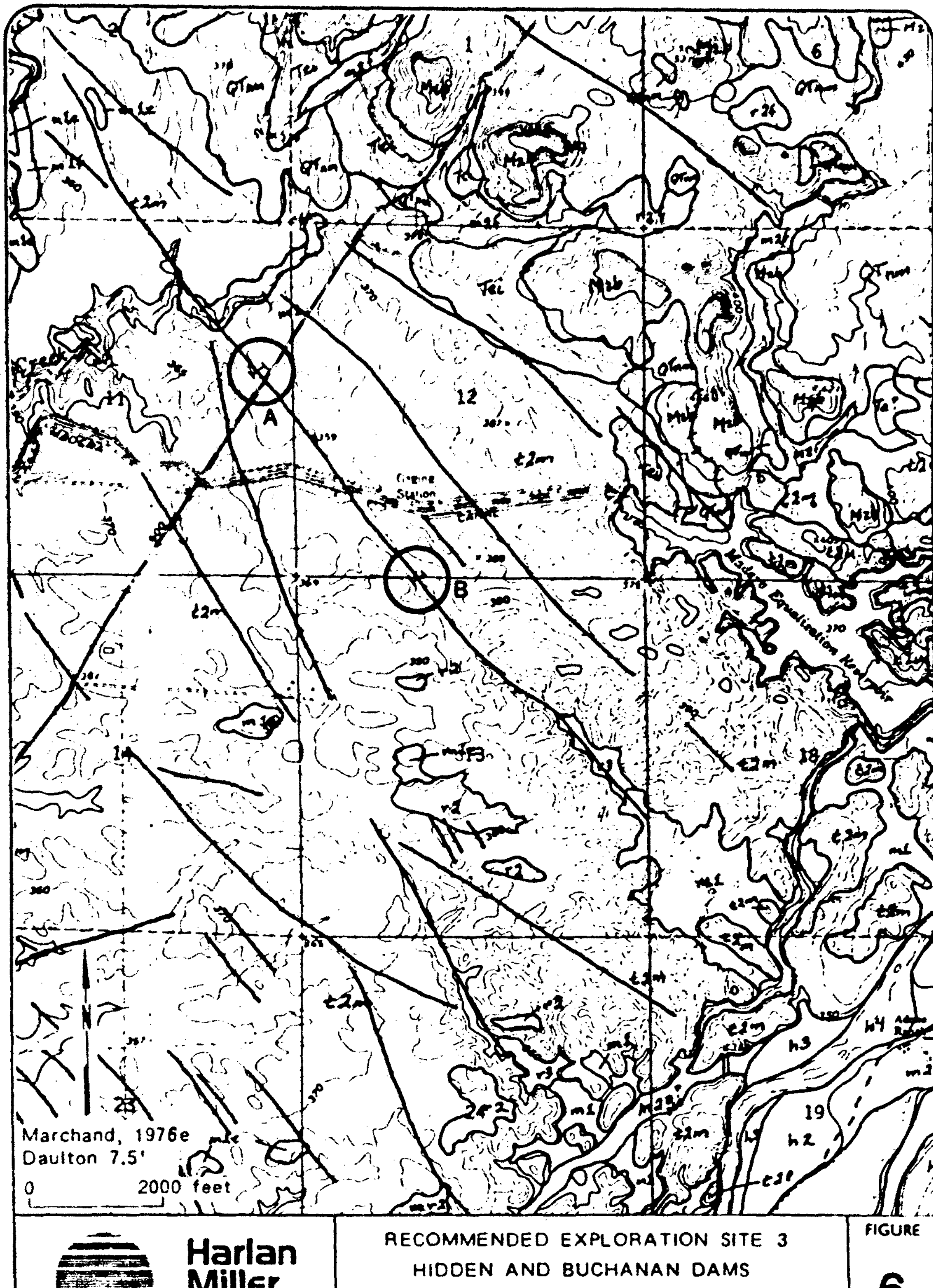
Proj No 437.05 Date 9/16/87 App'd by R. H. W.

vertical offset of stratification in the Turlock Lake Formation (minimum about 400,000 years old) across an area covered by slough. The road-cut should be cleaned and logged. In addition, a moderately deep (five to ten feet), relatively short (100± feet) trench should be placed across the projection of the inferred fault immediately north of the road cut, and logged in detail.

3. Exploration Site 3

Site 3 is considered moderate priority and is recommended for trenching and detailed logging, and consists of two alternative sites (Figure 6). Alternative A is located in a field in the NE¼ of Section 11, T10S, R18E just northeast of Road 600, and Alternative B is located in a field in the NW¼ of Section 13, T10S, R18E about 1,100 feet south of the Madera Canal, both on the Daulton, California 7.5' Quadrangle. The alternatives are located to investigate one of the most prominent northwest-trending lineaments in the area (Marchand, 1976e), and the results will be useful in explaining the origin of similar northwest-trending lineaments in the area.

Alternative B is preferred, but at either location, the trench should be oriented northeast-southwest perpendicular to the lineament (E6-1, Plate 1). The lineament is identifiable on the ground as a lineal swale/drainage, and the trench should be placed as close as possible to a drainage divide. A trench at either location should encounter the Turlock Lake Formation (minimum about 400,000 years old) at moderate depth (five to ten feet deep), and should be long enough, about 250 to 500 feet, to expose the soil profile underlying the geomorphic surface adjacent to the swale/drainage.



Harlan Miller Tait

RECOMMENDED EXPLORATION SITE 3
HIDDEN AND BUCHANAN DAMS
Central California

FIGURE 6

Proj No: 437.05 Date: 9/16/87 App'd by: R.H.W.

Harlan Miller Tait

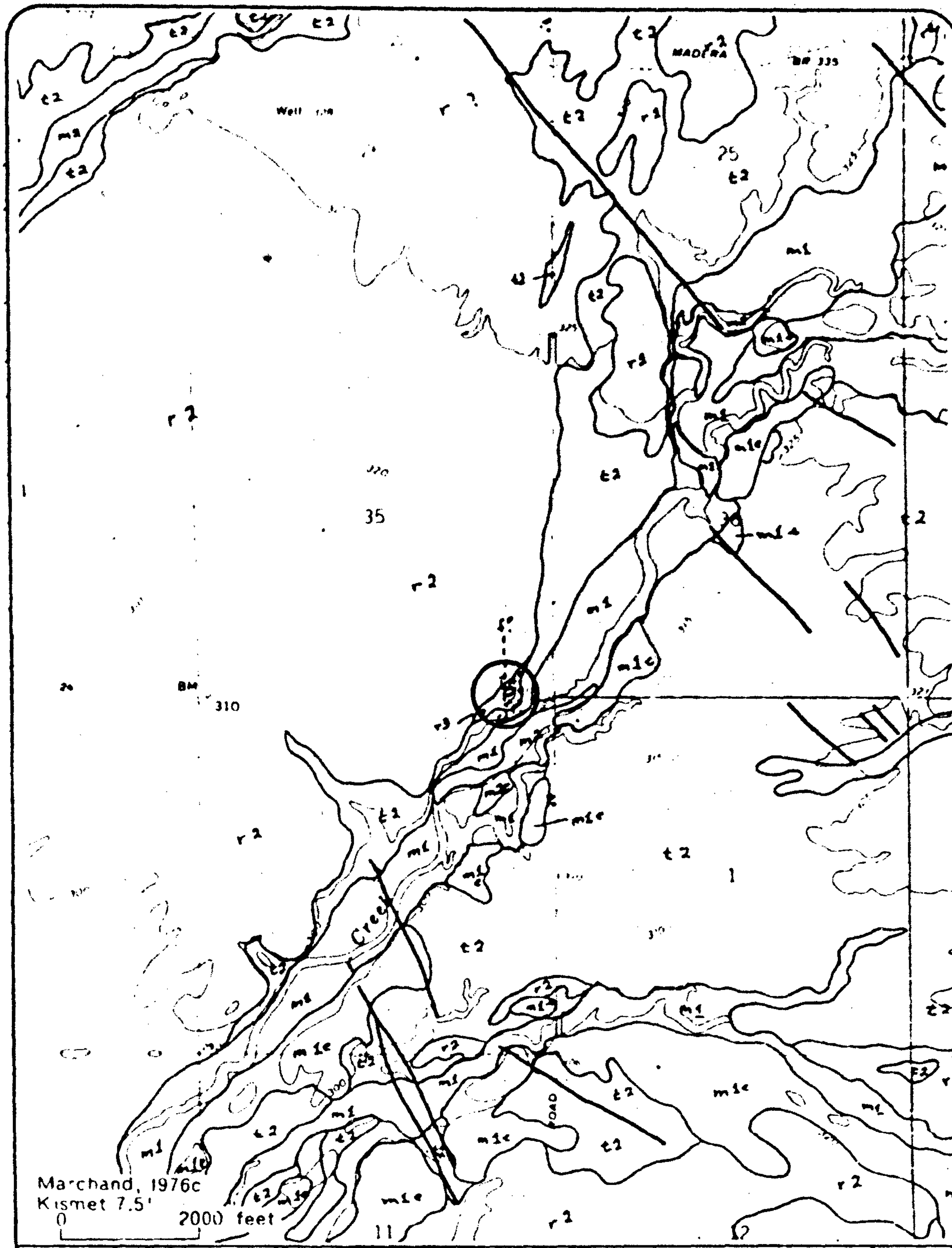
4. Exploration Site 4

Site 4 is recommended for cleaning and logging of a road-cut exposure. The site is located on the northwest side of Berenda Creek in the SE¼ of Section 35, T10S, R17E on the Kismet, California 7.5' Quadrangle, on the north side of Avenue 24, about 700 feet west of the intersection with Road 26 (Figure 7). The site is located to investigate the short north-trending inferred fault in the study area (Marchand, 1976c), and the results can document or refute the presence of the inferred fault mapped at this location.

No expression of faulting was observed during field reconnaissance, and the inferred fault (D6-1, Plate 1) is not associated with a topographic saddle or drainage in contrast with about all other lineaments in the area. Materials in the road-cut exposure appear to be continuous and consist of about ten feet of late Riverbank Formation sediments with a duripan, overlying either older Riverbank or late Turlock Lake Formation sediments. A probable buried paleosol (reddish brown with argillic horizon) is exposed in the western end of the cut. The road-cut exposure should be cleaned and logged to document the continuity of the sediments.

5. Exploration Site 5

Site 5 is considered low priority and is recommended for trenching and detailed logging, and consists of two alternative sites (Figure 8). Alternative A is located in a field in the SW¼ of Section 12, T9S, R17E just southeast of Road 26, and Alternative B is located in a field in the NW¼ of Section 13, T9S, R17E, both on the Raynor Creek 7.5' Quadrangle. The alternatives are located to investigate one of the most prominent north-

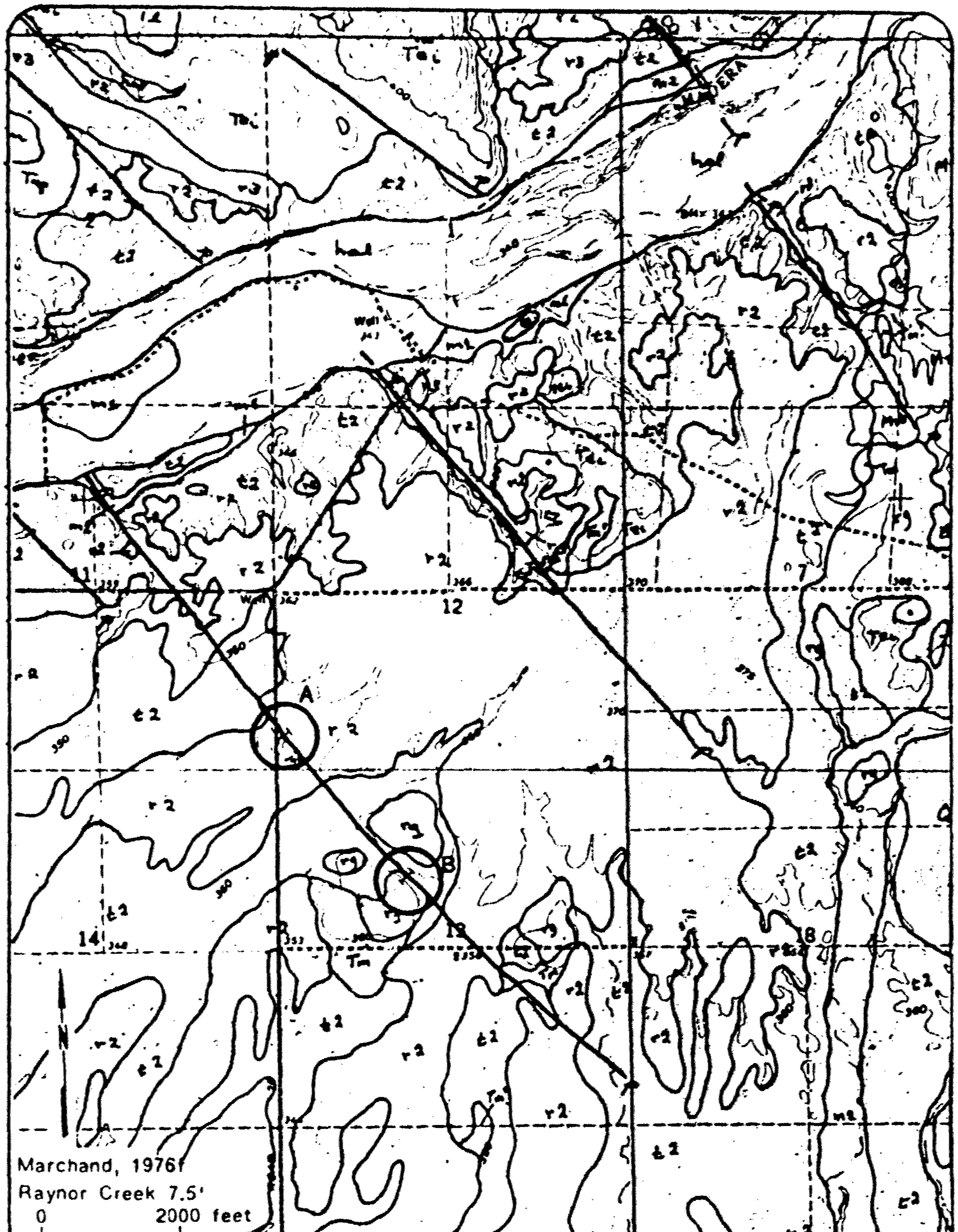


Harlan Miller Tait

RECOMMENDED EXPLORATION SITE 4
HIDDEN AND BUCHANAN DAMS
Central California

FIGURE 7

Proj No 437.05 Date 9/16/87 App'd by: RHW



Harlan Miller Tait

RECOMMENDED EXPLORATION SITE 5

HIDDEN AND BUCHANAN DAMS

Central California

FIGURE 8

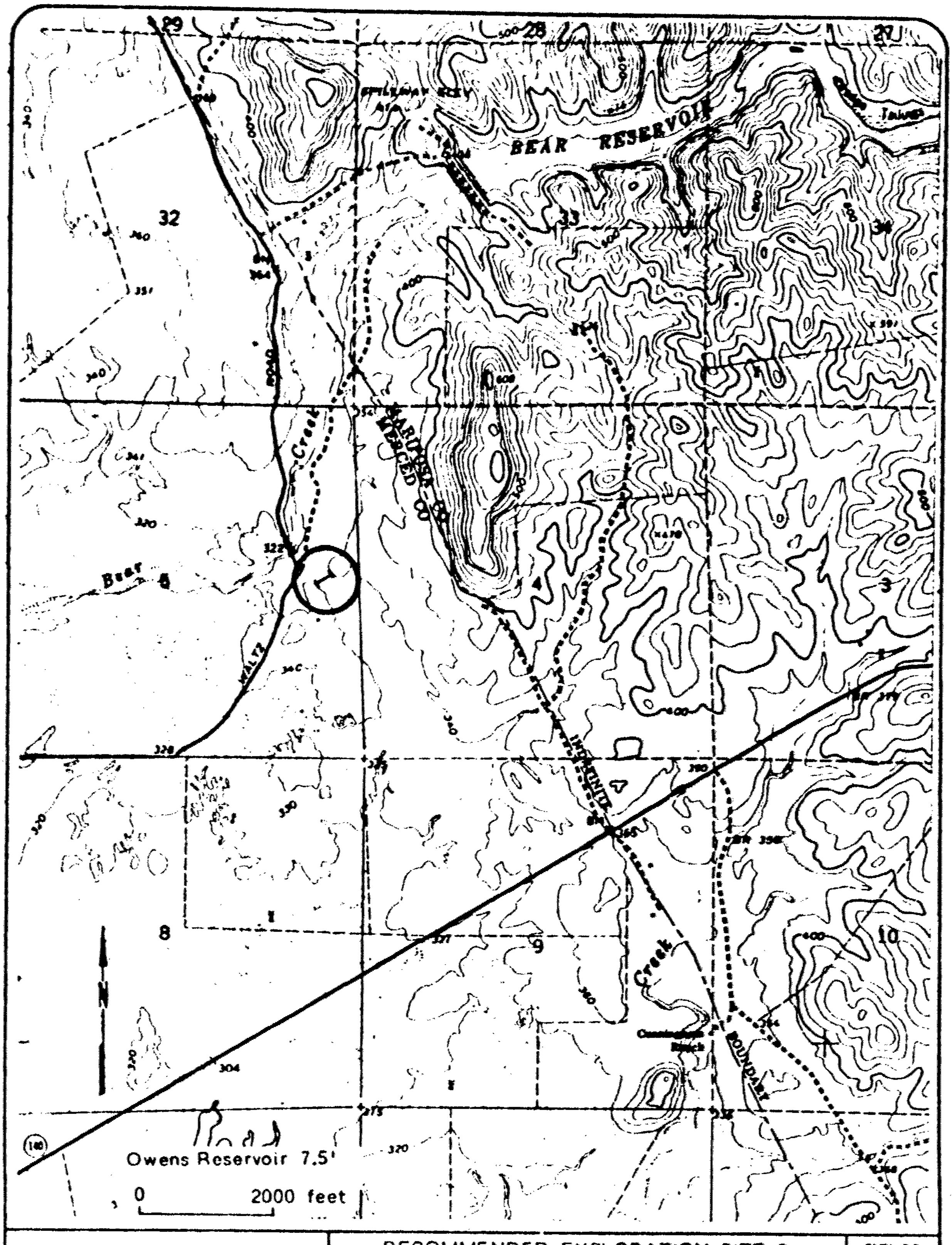
Proj No 437.05 Date 9/16/87 App'd by R.H.W.

west-trending lineaments in the northern part of the study area (Marchand, 1976f), and the results will be useful in explaining the origin of similar northwest trending lineaments in the area.

Alternative B is preferred because the lineament (D5-1, Plate 1) is better expressed, but at either location the trench should be oriented northeast-southwest perpendicular to the lineament, which is expressed on the ground as relatively diffuse and discontinuous saddles and swales, and placed as close as possible to a drainage divide. A trench at Alternative A should encounter Riverbank Formation sediments at shallow depth (±5 feet deep), and should be about 100 to 200 feet long. A trench at Alternative B should encounter Turlock Lake Formation sediments at moderate depth (five to ten feet deep), and should be sufficiently long, about 300 to 500 feet, to expose the soil profile underlying the geomorphic surfaces adjacent to the swale.

6. Exploration Site 6

Site 6 is considered high priority and is recommended for trenching and detailed logging. It is located in the east half of Section 5, T7S, R16E on Owens Reservoir, California 7.5' Quadrangle in an unplowed/undisturbed field off Waltz Road north of Highway 140 (Figure 9). The site is located to investigate the most prominent northwest-trending inferred fault in the northern part of the study area (Marchand, 1976a), and the results can document or refute the presence of the inferred fault mapped at this location, and be useful in explaining the origin of other northwest-trending projecting and parallel lineaments in the area, including the County Line postulated fault.



Harlan Miller Tait	RECOMMENDED EXPLORATION SITE 6 HIDDEN AND BUCHANAN DAMS Central California	FIGURE **9**
	Proj No. 437.05 Date: 9/16/87 App'd by: R.H.W.	

Harlan Miller Tait

The inferred fault (C4-1, Plate 1) is expressed as a linear swale/drainage south of and tributary to Bear Creek. The trench should be oriented northeast-southwest perpendicular to the axis of the swale/drainage, and placed on a low drainage divide about 400 feet east of Waltz Road. The trench should encounter Turlock Lake Formation sediments or North Merced Gravel as a veneer capping the Ione Formation at a relatively moderate depth (five to ten feet deep), and should be long enough, about 200 to 300 feet, to expose the soil profile underlying the adjacent geomorphic surface to the east.

Harlan Miller Tait

V. REFERENCES

Antonnen, G. J., E. A. Danehy, and J. A. T. Fallin, 1974, The Kings Canyon Lineament: Across grain lineament in Central California: Proceedings of First International Conference on the New Basement Tectonics, Utah Geological Association Publication, 5 p., 81-93.

Arkley, R. J., 1962a, The geology, geomorphology, and soils of the San Joaquin Valley in the vicinity of the Merced River, California: in Geologic Guide to the Merced Canyon and Yosemite Valley, California, California Division of Mines and Geology, Bulletin 182, p. 25-32.

Arkley, R. J., 1962b, Soil Survey, Merced County, California: U.S. Department of Agriculture, Soil Conservation Service, Series 1950, no. 7.

Axelrod, D. I., 1957, Late Tertiary floras and the Sierra Nevada uplift (California-Nevada): Geological Society of American Bulletin, v. 68, no. 1, p. 19-45.

Bartow, J. A., 1979, Constraints on the latest movements on the Melones Fault Zone, Sierra Nevada Foothills, California: U.S. Geological Survey Professional Paper 1126, p. J1-J4.

Bartow, J. A., 1980, Map and Cross Sections showing Tertiary Stratigraphy and Structure of the Northern San Joaquin Valley, California: U.S. Geological Survey Miscellaneous Field Studies Map, MF-1761, 1 sheet, scale 1:250,000.

Bartow, J. A., 1983, Map showing configuration of the Basement Surface, Northern San Joaquin Valley, California: U.S. Geological Survey, Miscellaneous Field Studies Map, MF-1430, 1 sheet, scale 1:250,000.

Bateman, D. C., A. J. Buscana, D. E. Marchand, and W. N. Sauka, 1983, Geologic Map of the Raymond Quadrangle, Madera and Mariposa Counties, California: U.S. Geological Survey Quadrangle Map GQ-1555.

Bateman, P. C., C. Wahrhaftig, 1966, Geology of the Sierra Nevada, in Geology of Northern California: California Division of Mines and Geology, Bulletin 190, p. 107-172.

Bayoumi, A. R. I., 1961, Gravity and magnetic study in the San Joaquin Valley: Stanford University, Ph.D. thesis, 45 p.

Berggren, W. A., 1972, A Cenozoic time scale -- some implications for regional geology and paleobiogeography: Lethaia, v. 5, no. 2, p. 195-215.

Blake, M. C., Jr., I. Zietz, and D. L. Daniels, 1977, Aeromagnetic and generalized geologic map of parts of central California: U.S. Geological Survey Geophysical Investigations Map GP-918.

Bryant, W. A., 1983, Southern foothills fault system, Amador, Calaveros, El Dorado, and Tuolumne Counties: California Division of Mines and Geology Fault Evaluation Report FER-148, 12 p.

Butler, C. S., and G. S. Jones, 1974, Soil Survey of Mariposa County Area, California: U.S. Department of Agriculture, Soil Conservation Service.

Clark, L. D., 1960, Foothills fault system, western Sierra Nevada, California: Geological Society of America Bulletin, v. 71, p. 483-496.

Clark, L. D., 1964, Stratigraphy and Structure of Part of the Western Sierra Nevada Metamorphic Belt of California: U.S. Geological Survey Professional Paper 410, 70 p.

Cloos, E., 1932, Structural survey of the granodiorite south of Mariposa, California: American Journal of Science, vol. 23, no. 136, p. 289-304.

Dalrymple, G. B., 1963, Potassium-argon Dates of some Cenozoic Volcanic Rocks in the Sierra Nevada, California: GSA Bulletin, v. 74, no. 4, p. 379-390.

Davis, F. F., and D. W. Carlson, 1952, Mines and Mineral Resources of Merced County: California Journal of Mines and Geology, v. 48, no. 3, p. 207-251.

Davis, P. S. Smith, G. S. Kukla, and N. D. Opdyke, 1977, Paleomagnetic study at a nuclear power plant near Bakersfield, California: Quaternary Research, v. 7, p. 380-397.

Davis, S. N., and F. R. Hall, 1959, Water quality of eastern Stanislaus and northern Merced Counties, California: Stanford University Publications, Geological Sciences, v. 6, no. 1, 112 p.

Duffield, W. A., and R. V. Sharp, 1975, Geology of the Sierra Foothills melange and adjacent areas, Amador County, California: U.S. Geological Survey Professional Paper 827, 30 p.

Ehrriech, A. L., 1965, Metamorphisen, Migmatization and Intrusion in the Foothills of the Sierra Nevada, Madera, Mariposa and Merced County, California: California University, Los Angeles, Ph.D. thesis, 272 p.

Frink, J. W., and H. A. Kues, 1954, Corcoran clay, a Pleistocene lacustrine deposit in the San Joaquin Valley, California: Amer. Petrol. Geologists Bull., v. 38, p. 2357-2371.

Fugro, Inc., 1974, Summary report, Phase II - Central San Joaquin Valley Nuclear Power Plant Siting Study: unpublished report, submitted to PG&E Co., San Francisco, California, by Fugro, Inc., Redwood City, California, 52 p.

Hansen, R. O., and E. L. Begg, 1970, Age of Quaternary sediments and soils in the Sacramento area, California by uranium and actinium series dating of vertebrate fossils: Earth Planetary Science Letters, v. 8, p. 411-419.

Harden, J. W., and D. E. Marchand, 1977, The soil chronosequence of the Merced River area, in Singer, M. J., ed., Soil development, geomorphology, and Cenozoic history of the northeastern San Joaquin Valley and adjacent areas, California: U.C. Davis, Guidebook for Joint Field Session, Soil Sci. Soc. America and Geol. Soc. America, p. 22-38.

Harden, J. W., 1982, A study of soil development using the geochronology of Merced River deposits, California: Ph.D. Dissertation, University of California, Berkeley, 237 p.

Harlan Miller Tait Associates, 1987, Field Technical Review, Success/Terminus Dams Fault Study"; letter report to U.S. Army Corps of Engineers, Sacramento District, dated February 3, 1987, 3p.

Helley, E. J., 1967, Sediment transport in the Chowchilla River Basin: Mariposa, Madera and Merced Counties, California: Ph.D. Dissertation, University of California, Berkeley, 153 p.

Harlan Miller Tait

Helley, E. J., 1978, Geologic map of the alluvial fan of the Chowchilla River and adjacent foothill area: U.S. Geological Survey Miscellaneous Field Studies Map MF-927, scale 1:62,500.

Hodges, C. A., 1979, Preliminary map of photolineaments along parts of the western Sierra Nevada foothills and eastern Coast Range foothills, CA, based on Landsat images and U-2 aircraft photographs: U.S. Geological Survey Open File Series, OF 79-1470, scale 1:250,000.

Hudson, F. S., 1960, Post-Pliocene uplift of the Sierra Nevada, California: Geological Society of American Bulletin, v. 71, p. 1547-1575.

Hunter, G. W., 1952; Riverdale Oil Field: California Department of Natural Resources, Division of Oil and Gas, Summary of Operations, California Oil Fields, v. 38, No. 2, p. 19-24.

Huntington, G. L., 1971, Soil survey, eastern Fresno area, California: U.S. Department of Agriculture, Soil Conservation Service.

Janda, R. J., 1965, Quaternary alluvium near Friant, California: Internat. Assoc. Quaternary Research Guidebook for Field Conference I, northern Great Basin and California, p. 128-133.

Janda, R. J., 1966, Pleistocene history and hydrology of the Upper San Joaquin River, California: Ph.D. Dissertation, Univeris., of California, Berkeley, 459 p.

Janda, R. J., and M. G. Croft, 1967, The stratigraphic significar.e of a sequence of Noncalcic Brown soils formed on the Quaternary alluvium of the northeastern San Joaquin Valley, California: in International Association Quaternary Research, Quaternary Soils: Internat. Assoc. Quaternary Research, VII Cong., Reno, Nev., Proc., v. 9, p. 158-190.

Jennings, C. W., 1975, Fault Map of California: California Division of Mines and Geology, California Geologic Data Map Series, Map No. 1.

Loken, K. P., 1959, Gill Ranch Gas Field: California Division of Oil and Gas, Summary of Operations, v. 45, no. 1, p. 27-32.

Marchand, D. E., 1976a, Preliminary geologic maps showing Quaternary deposits of the Merced area, eastern San Joaquin Valley, Merced County, California: U.S. Geological Survey Open-File Series 76-837, 7 sheets, scale 1:24,000.

Marchand, D. E., 1976b, Preliminary geological maps showing Quaternary deposits of the Madera area, eastern San Joaquin Valley, Madera and Fresno Counties, California: U.S. Geological Survey, Open-File Report 76-841, 8 sheets, scale 1:24,000 and report, 12 p.

Marchand, D. E., 1976c, Preliminary geologic maps showing Quaternary deposits of the Chowchilla area, eastern San Joaquin Valley, Madera and Merced Counties, California: U.S. Geological Survey Open-File Series 76-839, 5 sheets, scale 1:24,000.

Marchand, D. E., 1976d, Preliminary geologic maps showing Quaternary deposits of the northern Merced area, eastern San Joaquin Valley, Merced and Stanislaus Counties, California: U.S Geological Survey Open-File Series 76-836, 8 sheets, scale 1:24,000.

Marchand, D. E., 1976e, Preliminary geological maps showing Quaternary Deposits of the Paulton area, eastern San Joaquin Valley, Madera County, California: U.S. Geological Survey, Open-File Report 76-840, 4 sheets, scale 1:24,000 and report, 12 p.

Marchand, D. E., 1976f, Preliminary geologic maps showing Quaternary deposits of the southern Merced area, eastern San Joaquin Valley, Merced and Madera Counties, California: U.S. Geological Survey Open-File Series 76-838, 7 sheets, scale 1:24,000.

Marchand, D. E., 1977, The Cenozoic history of the San Joaquin Valley and the adjacent Sierra Nevada as inferred from the geology and soils of the eastern San Joaquin Valley: in Singer, M. J., ed., Soil development, geomorphology, and Cenozoic history of the northeastern San Joaquin Valley and adjacent areas, California: University of California, Davis, Guidebook for Joint Field Session, Soil Science Society of America and Geological Society of America, p. 39-50.

Marchand, D. E., and A. Allwardt, 1978, Quaternary deposits of the northeastern San Joaquin Valley, California: U.S. Geological Survey Miscellaneous Field Study Map MF-945, scale 1:125,000.

Marchand, D. E., and A. Allwardt, 1981, Late Cenozoic stratigraphic units, northeastern San Joaquin Valley, California: U.S. Geological Survey Bulletin 1470, 70 p.

McFadden, L. D., and R. J. Weldon, II, 1987, Rates and processes of soil development on Quaternary terraces in Cajon Pass, California: Geology, v. 98, no. 3, p. 280-293.

Moores, E. M., and H. W. Day, 1984, Overthrust model for the Sierra Nevada: Geology, v. 12, p. 416-419.

Nokleberg, W. J., 1983, Wallrocks of the Central Sierra Nevada Batholith, California, A collage of acreted tectono-stratigraphic terranes: U.S. Geological Survey Professional Paper 1255, 28 p.

O'Neill, A. L. 1987, Success and Terminus Dams major fault study; letter report to U.S. Army Corps of Engineers, Sacramento District, dated January 29, 1987, 4 p.

Oliver, H. W., and W. F. Hanna, 1970, Structural significance of gravity and magnetic meganomalies in central California: Geological Society of America, Abstracts with Programs, v. 2, no. 2, p. 126-127.

Pacific Gas and Electric Company, 1977, Notice of Intention for Stanislaus Nuclear Project alternate sites: Merced, Madera: submitted to California State Energy Resources Conservation and Development Commission, v. I and II.

Page, R. W., and R. A. LeBlanc, 1969, Geology hydrology, and water quality in the Fresno Area, California: U.S. Geological Survey Water Resources Division Open-File Report, 70 p.

Paterson, S. R., O. T. Tobisch, J. K. Radloff, 1987, Post-Nevadan deformation along the Bear Mountains fault zone: Implications for the Foothills terrane, Central Sierra Nevada, California: Geology, v. 15, p. 513-516.

Piper, A. M., H. S. Gale, H. E. Thomas, and T. W. Robinson, 1939, Geology and Groundwater Hydrology of the Mokelumne Area, California: U.S. Geological Survey Water Supply Paper 780, 230 p.

Rogers, T. H., 1966, Geologic Map of California, Olaf P. Jenkins edition, San Jose Sheet: California Division of Mines and Geology, Scale 1:250,000.

Saleeby, J. B., 1975, Structure, petrology and geochronology of the Kings-Kaweah mafic-ultramafic belt, southwest Sierra Nevada, California: Ph.D. Dissertation, University of California, Santa Barbara, 286 p.

Saleeby, J. B., 1978, Kings river ophiolite, southwest Sierra Nevada foothills, California: Geological Society of America Bulletin, v. 89, p. 617-636.

Saleeby, J. B., 1979, Kaweah serpentine melange, southwest Sierra Nevada foothills: Geological Society of America Bulletin, v. 90, p. 29-46.

Saleeby, J. B., S. E. Goodin, W. D. Sharp, and C. J. Busby, 1978, Early Mesozoic paleotectonic - paleogeographic reconstruction of the southern Sierra Nevada region: in Mesozoic paleogeography of the western United States: Pacific Coast Paleogeography Symposium 2, p. 311-336.

Schweickert, R. A., J. B. Saleeby, O.T. Tobisch, and W. H. Wright, 1977, Paleotectonic and paleogeographic significance of the Calaveras Complex, western Sierra Nevada, California: in Paleozoic paleogeography of the western United States: Pacific Coast Paleogeographic Symposium 2, p. 381-394.

Shackleton, N. J., and N. D. Opdyke, 1973, Oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperature and ice volumes on a 10^5 and 10^6 year scale: Quaternary Research, v. 3, no. 1, p. 39-55.

Shlemon, R. J., 1967, Quaternary geology of northern Sacramento County, California: Geological Society Sacramento Ann. Field Trip Guidebook, 60 p.

Shlemon, R. J., 1972, The lower American River area, California: A model of Pleistocene landscape evolution: Assoc. Pacific Coast Geographers Yearbook, v. 34, p. 62-86.

Harlan Miller Tait

Shlemon, R. J., 1985, Application of soil-stratigraphic techniques to engineering geology: Association of Engineering Geologists Bulletin VXXII, no. 2, p. 129-142.

Shlemon, R. J., 1986, Age of Quaternary sediments and soils, fault study trenches FS-2 (Deer Creek), and FS-3, -4 and -5 (Frazier Valley, Tulare County, California): for U.S. Army Corps of Engineers, Sacramento District, 5 p.

Singer, M. J. (ed.), 1977, Soil development, geomorphology, and Cenezoic history of the northeastern San Joaquin Valley and adjacent areas, California: A guidebook for the Joint Field Session of the American Society of Agronomy, Soil Science Society of America, and the Geological Society of America.

Slemmons, D. B., 1966, Cenozoic Volcanism of the Central Sierra Nevada California, in Bailey, E. H. (ed), Geology of Northern California: CDMG Bulliten 190, p. 199-208.

Strand, R. G., 1967, Geologic Map of California, Olaf P. Jenkins edition, Mariposa Sheet: California Division of Mines and Geology, Scale 1:250,000.

Tierra Engineering Consultants, Inc., 1983, Geologic and Seismologic Investigation of the Folsom, California Area: Report to U.S. Army Corps of Engineers, Sacramento District (Contract No. DACW05-82-C-0042).

Ulrich, R., and L. K. Stromberg, 1962, Soil survey of Madera County area, California: U.S. Department of Agriculture, Soil Conservation Service.

U.S. Army Corps of Engineers, 1979, Geologic reconnaissance of the Kings-Kaweah suture: U.S. Army Corps of Engineers, Sacramento District, 11 p.

U.S. Army Corps of Engineers, 1985a, Geologic reconnaissance of the Buchanan Dam and Eastman Lake Area: U.S. Army Corps of Engineers, Sacramento District, 7 p.

U.S. Army Corps of Engineers, 1985b, Geologic reconnaissance of the Hidden Dam and Hensley Lake area: U.S. Army Corps of Engineers, Sacramento District, 7 p.

U.S. Geological Survey, 1983, Aeromagnetic map of the southern and central Nevada foothills and adjacent San Joaquin Valley, CA: U.S. Geological Survey Open File Series, OF 83-55, scale 1:62,500, 7 sheets.

Wentworth, C. M., M. D. Zoback, A. Griscom, R. C. Jachens, and W. A. Mooney (in press), A transect across the Mesozoic accretionary margin of Central California: Geophysical Journal of the Royal Astronomical Society.

Wong, I. G., and W. U. Savage, 1983, Deep intraplate seismicity in the western Sierra Nevada, Central California: Bulletin of the Seismological Society of America, v. 73, no. 3, p. 797-812.

Woodward-Clyde Consultants, 1975, Merced Area, in Phase II, Regional seismicity and fault study: unpublished report submitted to Pacific Gas and Electric Company, San Francisco, California, v. 5, 116 p.

Zoback, M. D., and C. M. Wentworth, 1986, Crustal studies in central California using an 800-channel seismic reflection recording system: Reflection Seismology: A Global Perspective: American Geophysical Union, Geodynamic Series, v. 13, p. 183-196.

Harlan Miller Tait

APPENDIX A

LINEAMENT STUDY

437A:05(54)

Harlan Miller Tait

SURFICIAL LINEAMENTS

HIDDEN AND BUCHANAN DAMS

Prepared for

Harlan Miller Tait Associates
San Francisco, California

July 1987

by

Photographic Interpretation Corporation
13 Dartmouth College Highway
Lyme, New Hampshire 03768

437A:05(55)

Harlan Miller Tait

SURFICIAL LINEAMENTS

HIDDEN AND BUCHANAN DAMS

INTRODUCTION

The Photographic Interpretation Corporation (PIC) has conducted an independent surface lineament mapping study using aerial imagery of the area surrounding the Hidden and Buchanan Dams, which are in the foothills of the Sierras in the vicinity of Fresno and Merced, California. The study area, a rectangle with corners at 37° 45'N 120° 00'W, 37° 20'N 120° 30'W, 36° 45'N 119° 45'W, and 37° 7.5'N 119° 15'W, encompasses approximately 1,700 square miles and includes portions of the Sierra Nevada foothills and the San Joaquin section of the Central Valley. The study made use of various forms of aerial imagery including Skylab photos, Side-Looking Airborne Radar (SLAR), Color Infrared (CIR) photos, and Panchromatic prints from CIR originals taken for the National High-Altitude Photo (NHAP) program.

The results of this study are presented in this report. Photos and photomosaics, and accompanying alternate photos and lineament overlays for the various sets of imagery used in the analysis, are submitted separately as Data Set 1.

In 1911, Hobbs[1] began the systematic analysis of linear landscape features using maps and the idea of viewing the terrain from heights. In 1958, Lattman[2] described a technique of mapping these linear features, or lineaments, on aerial photographs and, in 1964, Boyer and McQueen[3] reported on a systematic comparison of photo-derived lineaments with actual surface geologic mapping and concluded that:

> "...the results of this study indicate a close parallelism of fractures measured on the ground and airphoto linear features and suggest that the airphoto linear features are largely a reflection of fractures in the rocks emphasized by vegetation and topography."

PIC has conducted over a dozen studies in California and throughout the United States using these same techniques.

Lineaments mapped from aerial imagery do not necessarily represent geologic faults. They may only reflect bedrock joint and fracture patterns without implying movement. Segments of lineaments are often aligned with the drainage pattern which is influenced by fractures or other weak zones in the bedrock. Conversely, segments of known faults, especially those of a low angle (e.g., thrust faults), are not always reflected as either drainageways or as topographic features recognizable on the airphotos.

To avoid being influenced by existing data, this study was conducted without prior consultation with the report of Hodges[4], who made use of Landsat and high-altitude photographic imagery to map photolineaments throughout the mountains on either side of the Central Valley. A comparison of results suggests some similarity and several differences in the locations and numbers of lineaments detected.

DATA SOURCES

Fourteen known imagery types and scales were investigated prior to beginning this study. Of these, five were chosen as representative of the range of scales and image types, as being available in the relatively short time available for the study, and as being cost effective with respect to the constraints of money and time.

The images used in this study and their sources are shown in Table A-I and discussed below:

Table A-I

Images Used for Lineament Detection

	Image	Date	Scale	Format	Emulsion	Source
1.	SLAR	--	1:400,000	Strip	Pan	EDC
2.	Skylab	1973	1:250,000	18"x18"	CIR	EDC
3.	CIR	--	1:130,000	9"x9"	CIR	NASA Ames
4.	Skylab	1973	1:125,000	36"x36"	CIR	EDC
5.	NHAP	1983-85	1:58,000	9"x9"	CIR	USDA

1 SLAR Images (1:400,000) - PIC was able to locate some Side-Looking Airborne Radar images of the study area which were taken as a part of another study by the USGS. This imagery offered a different perspective of the terrain - that of high-altitude, oblique, electromagnetic illumination. This type of imagery tends to enhance terrain lines which are oriented parallel to the line of flight (east-west). Lines perpendicular to the line of flight are less enhanced. Because of the very small scale of these images, only major lineaments are seen, and the transfer to the larger base map scale is difficult.

2/4 Skylab Images (1:250,000 & 1:125,000) - 1973 Skylab images (hand-held photographs taken from the Skylab satellite) were chosen as the small-scale photographic base because they can be viewed in stereo, and because they are color infrared (CIR) photographs, not digital images as Landsat. The original five-inch negatives were enlarged to

18 by 18 inches for stereoscopic viewing and 36 by 36 inches for monoscopic viewing and evaluation. The larger image was also useful as a medium for comparison to the base maps as they were most nearly the same scales.

3 <u>NASA Ames CIR Photographs (1:130,000)</u> - Two flight strips of high-altitude CIR vertical, stereoscopic photographs covering about 80 percent of the study area were obtained from EROS Data Center. The strips were laid out to form a stereoscopic (using only the alternate prints) mosaic. The linears detected on these photos were mapped on clear mylar overlays to the mosaic and transferred to the base map after comparison with those from the other imagery.

5 <u>NHAP Panchromatic Photographs (1:58,000)</u> - National High Altitude Photography was obtained from the U.S. Department of Agriculture Photo Lab as 9 x 9 inch panchromatic prints of CIR images. Approximately 95 photos were combined as an uncontrolled stereoscopic mosaic, which allowed the entire study area to be viewed in three dimensions.

This mosaic was used to create a detailed drainage overlay, which was in turn analyzed to determine if there were lineaments observable in the drainage patterns. The locations of streams and gullies are often controlled by the underlying bedrock, where these rocks are jointed and fractured. In addition, faults are often reflected by offsets in adjacent drainageways. A detailed mapping of surficial drainage in a region emphasizes these abrupt changes in the alignment of streams

and stream channels, thus providing good clues about the geologic structure.

METHODOLOGY

The lineament analysis for the project was accomplished by a geologist and a civil engineer experienced in the interpretation of aerial imagery and in lineament analysis. The lineament overlays of the two interpreters were compared and the aerial images reexamined when there was a difference of opinion. After careful consideration, each linear was either included on a composite overlay for each image or eliminated from further consideration.

All overlays were then compared to each other and to existing maps to determine if the lineaments noted on each image type were noted on one or more others and to determine if there was some cultural reason for a linear feature to occur, such as a road, fence line, or change in land-use or cover.

When the interpreted lineaments were determined to be naturally occurring, and when they were apparent on two or more different sets of imagery, or when they occurred on only one image but were extremely strong, they were located on the base map and included in the final mapping. Thus, only thos features which appear to be bedrock-related are shown on the final map. However, all of the lineaments noted, whether depicted on the final maps or not, are on the overlays submitted as a part of Data Set I.

Harlan Miller Tait

Table A-II

Contents of Data Set I

1. Photomosaic of four (4) 1:400,000-scale 2 x 20 inch SLAR images and lineament overlay

2. Two (2) 1:250,000-scale 18 x 18 inch Skylab CIR images and lineament overlay

3. Photomosaic of 1:130,000-scale 9 x 9 inch NASA Ames CIR images and lineament overlay, with alternative stereo images

4. One (1) 1:128,000-scale 36 x 36 inch Skylab CIR image and lineament overlay

5. Photomosaic of 1:58,000-scale 9 x 9 inch NAPA panchromatic images and drainage and lineament overlay (rolled), with alternative stereo images

RESULTS

The results of the independent analyses of the various remote-sensor images were then combined into the final lineament map presented with this report. Most of the lineaments depicted on the 1:100,000-scale base map are probably joints, fractures, or other planes of weakness in the bedrock and are only indications of general structural trends. (In fact, many of the lineaments noted follow the general structural and bedding trends in this portion of the foothill complex.) Others cross the normal bedrock trends or, although parallel, are so strong that they may indicate possible planes of movement. These should be compared to geologic maps and other lineament mapping in the area, and/or investigated in the field to determine their causes.

It is difficult to compare lineaments mapped from satellite imagery (Skylab) to those mapped from relatively large-scale photographs. The

Harlan Miller Tait

differences in scale necessitate that each analysis be based on different criteria. At the satellite scale, entire river valley systems extending for several miles may align themselves into one linear element, while at 1:58,000-scale, only straight segments of a river channel or a gully would be mapped as a lineament. Even the finest pen line will cover a width of several hundred feet on the ground, and at larger scales, that same line will be only a few feet wide. Thus, each image and image scale provides a different level of detail in the linears mapped.

Literature Cited

1. Hobbs, W. H., 1911, "Repeating Patterns in the Relief and in the Structure of the Land", Bull. G.S.A., Vol 22, pp. 123-176.

2. Lattman, L. H., 1958, "Techniques of Mapping Geologic Fracture Traces and Lineaments on Aerial Photographs", Photogrammetric Engineering, Vol 24, pp. 568-576.

3. Boyer, R. E., and J. E. McQueen, 1964, "Comparison of Mapped Rock Fractures and Airphoto Linear Features", Photogrammetric Engineering, Vol 30, No. 4, pp. 630-635.

4. Hodges, C. A., 1979, "Preliminary Maps of Photolineaments along Parts of the Western Sierra Nevada Foothills and Eastern Coast Range Foothills, California, Based on Landsat Images and U-2 Aircraft Photographs", U.S.G.S. Open File Report 79-1470.

APPENDIX B

ROY J. SHLEMON & ASSOC., INC.
Geological and Environmental Consultants

Post Office Box 3066
Newport Beach, California
U.S.A. 92663-0620
Tel. (714) 675-2696

Quaternary Geology
Economic Geomorphology
Soil Stratigraphy
Geoarchaeology

AGE OF QUATERNARY SEDIMENTS AND SOILS, FAULT AND LINEAMENT INVESTIGATIONS, MADERA AND MERCED COUNTIES, CALIFORNIA

Summary Report -- January 1988

by

Roy J. Shlemon

for

U.S. Army Corps of Engineers

(Sacramento District)

Contract No. DACW05-87-P-3958

January 1988

CONTENTS

AGE OF QUATERNARY SEDIMENTS AND SOILS, FAULT AND LINEAMENT INVESTIGATIONS, MADERA AND MERCED COUNTIES, CALIFORNIA

Summary Report -- January 1988

INTRODUCTION

The following summarizes field observations and conclusions concerning the age of Quaternary sediments and soils exposed in backhoe trenches excavated by the U.S. Army Corps of Engineers (USCE) at six sites in Madera and Merced counties, California. The trenches were emplaced across inferred faults and representative northwest-trending lineaments suggested to be possible expressions of Quaternary faulting (Marchand, 1976a, 1976b, 1976c, 1976d Marchand and Allwardt, 1978). The specific sites were identified and recommended by Harlan Miller Tait (HMT, 1987) based mainly on photogeologic interpretation and field reconnaissance.

Field observations for this study were carried out on September 30 and October 1, 1987 as part of a USCE-commissioned seismotectonic investigation to determine the possible presence and relative activity of faults in the environs of Hidden and Buchanan Dams. The trenches were logged by USCE geotechnical personnel who kindly made available preliminary logs for this summary. The logs and associated location maps are on file with the USCE (Sacramento District) and hence are not reproduced in this report.

Logistical support was provided by the Sacramento District of the USCE. Particularly helpful were the comments and field assistance provided by USCE geologists T. Fea, K. Jorgensen, R. Adams and R. Treat.

Trench sites 1 through 5 were in located Madera County; where sites 2 and 4 focused on published faults; and sites 1, 3 and 5 investigated the origin of major photolineaments. Trench site 6 was located in the southeastern part of Merced County in order to assess the origin of a photolineament coincident with "the County Line fault" of Marchand (1976d). Some investigative sites contained two or more parallel and sometimes overlapping trenches; others exposed mainly newly-cleaned roadcuts or natural outcrops (see USCE location maps). This summary, however, focuses only on exposures examined in detail and for which USCE logs are available.

QUATERNARY STRATIGRAPHIC FRAMEWORK

The distribution and age of Quaternary sediments along the east side of the Central Valley of California is now relatively well known (see, for example, summaries in Marchand and Allwardt, 1980; and Harden, 1987). In brief, three major Quaternary-age formations are recognized: Modesto (youngest), Riverbank, and Turlock Lake (Davis and Hall, 1959). These formations are subdivided into several members each usually consisting of basal channel gravels overlain by overbank and distributary deposits, and capped by diagnostic soils (pedogenic profiles). The distribution and

general age range of these formations is reasonably well known, based mainly on interpretations of soil surveys (Arkley, 1954, 1962a; Huntington, 1971; Ulrich and Stromberg, 1962), on limited radiometric dates (Hansen and Begg, 1972; Rosholt, 1980; Marchand and Allwardt, 1980), and on association with the marine isotope-stage and the Sierra Nevada glacial chronology (Arkley, 1962b; Janda and Croft, 1967; Shlemon, 1967, 1972; Marchand and Allwardt, 1980). The approximate age ranges for the respective formations are:

(1) Modesto: less than about 60,000 to 70,000 years old (isotope stages 2 through 4);

(2) Riverbank: about 125,000 to 400,000 years old (stages 5 through 10); and

(3) Turlock Lake: about 400,000 to probably somewhat in excess of a million years old.

The older formations are expressed geomorphically as increasingly dissected terrane which preserves less of the original surfaces and capping relict paleosols (HMT, 1987). However, as shown in the USCE trenches, post-Turlock Lake and post-Riverbank soils are commonly encountered as buried paleosols. And these soils often prove to be excellent stratigraphic markers to judge the age of underlying sediments, to date any faults which might be observed, and to assess the origin of non-tectonic photographic lineaments (Shlemon, 1985).

EXPLORATORY TRENCHES

Trench Site 1

Trench site 1 was chosen to determine the origin of a major, northwest-trending photographic lineament near the junction of Highway 41 and Avenue 11 in Madera County, immediately north of the San Joaquin River (Lanes Bridge Quadrangle; NW 1/4, NE 1/4, sec. 9; T. 12 S., R. 20 E; see also HMT [1937] and USCE location maps and logs). This lineament, inferred to be possibly fault-controlled (Marchand, 1976d; Marchand and Allwardt, 1978), corresponds to a broad swale gently sloping southwestward toward the now deeply-incised San Joaquin River (Janda, 1966).

The USCE emplaced two trenches across the swale: T-2, about 300 ft long, which encountered caving sands and was eventually abandoned; and T-1, some 240 ft long and aproximately 8 to 10 ft deep (USCE logs), which crossed the entire swale and exposed a datable soil-stratigraphy. Two major deposits were observed in T-1: (1) an upper 2 to 6-ft thick sequence of sands and silty sands; and (2) an underlying accumulation of fluvial sands locally capped by a moderately- to strongly-developed buried paleosol replete with silcrete duripan (2Bqmb horizon).

Previous regional mapping indicated that the swale incises the Riverbank formation (Janda, 1966), an assessment borne out by the presence of a strongly-developed relict paleosol capping adjacent surfaces. The upper swale sediments are mainly colluvial, derived from adjacent sideslopes. A slightly-developed soil caps most of these upper sediments indicating that this colluvium is probably of Modesto age.

As shown by gradient and by exposures in bluffs bordering the San Joaquin River, the swale apparently deepens southwestward to eventually bottom in sediments of Turlock Lake age. The swale thus most likely originated as a tributary to a more deeply-incised San Joaquin River, presumably in late Modesto time some 15,000 to 20,000 years ago (isotope stage 2), a phenomenon reported elsewhere in the Central Valley (Janda, 1966; Shlemon, 1972).

Trench T-1 logs show that there are no faults coincident with the swale. Thus the swale and its associated northwest-trending lineament are not likely of tectonic origin. Nevertheless, even if one were to postualte tectonic control of the lineament, the presence of unbroken Riverbank-age sediments indicates that last displacement would have had to taken place prior to at least about 125,000 years ago.

Trench Site 2

Trench site 2 was located near the intersection of Avenue 15 and Road 36 in Madera County (Gregg Quadrangle, SE 1/4, SE 1/4, sec. 16, T. 11 S., R. 19 E.). Here, two trenches were emplaced across a fault inferred from a shallow roadcut exposure (Marchand, 1976d). The trenches, approximately 180 and 100 ft long, respectively, were sited across the postulated fault in dissected Turlock Lake terrane.

Both trenches encountered basal cross-bedded sands and silts of the Turlock Lake formation locally overlain by post-Turlock Lake colluvium. The log of Trench 2-A shows particularly well the presence of an ancient, southeast-trending, steep-walled channel (USCE logs, station 44 through 60). The channel is at least 10 ft deep, and juxtaposes fluvial sands

against older, horizontally-bedded silts. Such a feature, if observed in a shallow roadcut, could well be interpreted as a possible fault. However, as shown by the USCE trenches excavated to over 10 ft, no faults were encountered; and a complex overlapping stratigraphy of Turlock Lake age is undisplaced.

Geomorphic evidence also suggests that there is no fault at this locality or, if one is present at depth, it is of great antiquity. First, there are no channels, swales, or photographic lineaments associated with the inferred fault. And second, there are many other northwest-southeast trending gullies and channel fills in the area which give rise to regional dissection of the Turlock Lake surface; and these features are also not fault related.

In sum, no fault has been found at site 2. Rather, the trenches reveal the presence of an ancient, intra-Turlock Lake channel which, in an uncleaned and shallow roadcut, may have been interepreted as a possible tectonic feature.

Trench Site 3

Trench 3, about 250-ft long, was sited across a major lineament and swale near Madera County Road 21 about 1,100 ft south of the Madera Canal (Daulton Quadrangle; NE 1/4, NW 1/4, sec. 13, T. 10. S., R. 18 E; see HMT [1987], and USCE logs and location maps).

The trench exposed two major deposits: (1) an upper sand and clayey sand ranging from about two-ft thick on flanks of the swale to near 6-ft thick in the center of the swale; and (2) a lower, interbedded sand and silt sequence capped by a reddish-brown, strongly-developed buried paleosol.

The upper sediments, typically brown to yellowish brown in color, bear only a slightly-developed soil profile, and are most likely colluvial deposits of Modesto age. In contrast, the underlying sediments bear a strongly-developed buried paleosol traceable almost continuously in the trench walls. This paleosol is characterized by a columnar claypan (argillic horizon) with moderately-thick continuous clay films coating ped faces (2Btb horizon). The claypan rests on an iron-silica duripan (2Bqmb horizon) likewise identified throughout most of the trench. Underlying oxidized 2Cb and 2Coxb horizons extend to almost four ft below the claypan, also attesting to strong pedogenic development and hence antiquity of the parent material. Little, if any, gravitational water penetrates the buried paleosol; rather it perches water as indicated by the presence of a thin, overlying and laterally extensive E horizon.

The buried paleosol, judging from its strong development, is at least 100,000 years old, and may well be the post-Riverbank soil in this area. Alternatively, it may be much older, having formed on Turlock Lake sediments. Regardless, it is an excellent stratigraphic marker, and because neither it nor its underlying sediments are displaced (USCE logs), any postulated fault controlling swale development in this area is at least 100,000 years old and probably much older.

Trench Site 4

Site 4 is an approximately 400-ft long roadcut on the north side of Madera County Avenue 24 near the intersection of Road 26 (Kismet Quadrangle; SE 1/4, SE 1/4, sec. 35, T. 9 S., R. 17 E; USCE logs and location maps). The site was selected to expose a previously-inferred

fault, apparently deduced by the presence of carbonate-filled fractures observed in a then, low and uncleaned roadcut (Marchand, 1976b).

The Site 4 roadcut was cleaned by backhoe and deepend to at least 10 ft. Two general stratigraphic sequences were exposed: (1) an upper sand bearing a strongly-developed relict paleosol with an iron-silica duripan (Bqm horizon); and (2) underlying sands and silty sands bearing a strongly-developed buried paleosol. These lower sediments frequently contain vertical, carbonate-filled fractures usually less than about 0.5 inches wide. These fractures do not offset lower unit beds, and are themselves truncated by the buried paleosol.

The upper sediments and diagnostic relict paleosol pertain to the Riverbank formation; the lower assemblage is thus probably of early Riverbank or, more probably, of Turlock Lake age. None of these sediments or soils are displaced (USCE logs). Further, the previously-inferred fault (Marchand, 1976b) would be coincident with a local drainage divide, rather than with a drainage swale typically indicative of the northwest-trending lineaments in this area. It thus appears that the inferred fault was, in reality, vertical, carbonate-filled fractures now shown to be non-tectonic in origin (USCE logs). Hence, because there are no observable faults at this locality, and because there are no lineaments or channels suggestive of possible offset, any postulated fault must be older than the unbroken Turlock Lake sediments; that is, probably greater than about 400,000 years old.

Trench Site 5

A 240-ft long trench was emplaced at Site 5 across a prominent, northwest-trending swale and photolineament, about two miles south of the Chowchilla River in Madera County (Raynor Creek Quadrangle, SE 1/4, NE 1/4, sec. 13, T. 9 S., R. 17 E). Here, two deposits were identified: (1) an upper 2 to 3-ft thick colluvium filling the swale (USCE log units 1 and 2); and (2) an underlying and unbroken series of silts and clayey sands capped by a strongly-developed buried paleosol (USCE log units 3 through 7).

The upper swale-filling sediments are fine-grained and bear a moderately-developed cumulic (accretionary) soil profile. The argillic horizon is characterized by strong, medium columnar structure, and thin but continuous clay films on ped faces. Carbonate nodules (stage II-III development; Gile and others, 1966) occur at the base of the upper sediments precipitated in a water table seasonally perched on the almost impervious underlying buried paleosol.

The lower sediments are traced continuously across the swale (USCE logs). Significantly, they are horizontal, and hence do not conform to swale topography. Their deposition therefore clearly pre-dates incision of the swale. Based mainly on induration, on topographic position and dissection, and on degree of soil profile development, these sediments are probably of Turlock Lake age. And, because they are unbroken, it is improbable that faulting gave rise to the Trench Site 5 swale and photographic lineament. More likely this swale, as well as others in the immediate area, were initially incised in Pleistocene time, and now are topographic lows slowly filling with sideslope colluvium.

Trench Site 6

Trench 6 crossed a broad swale near the Merced-Mariposa County line informally known as the "County Line lineament" (Owens Reservoir Quadrangle, SE 1/4, NE 1/4, sec. 5, T. 7 S., R. 16 E; Marchand [1976a]; Marchand and Allwardt, [1978]). The trench, 240-ft long and up to 12-ft deep, exposed a 10 to 11-ft thick clay overlying highly-foliated schists and felsic intrusive rocks. Locally, however, between station 24 and 36, the trench bottomed in fluvial sands and gravels (USCE logs).

The site geomorphic setting and trench stratigraphy indicate that the swale-filling clay is colluvial in origin, derived mainly from adjacent metamorphic bedrock. However, a few gravel stringers containing metamorphic clasts to 3-inches diameter occur near the edges of the trench. These sediments were apparently reworked from nearby outcrops of the North Merced Gravels and the Ione Formation (Arkley, 1962a; Marchand, 1976a; Marchand and Allwardt, 1981).

The colluvial clay also bears two and locally three calcium carbonate zones. The upper carbonate is diffuse, approximately 1-ft thick, and generally occurs within 1 to 2 ft from the modern surface (USCE logs). This carbonate probably reflects the present depth of significant moisture penetration though the clayey (vertisolic) colluvium (Arkley, 1963). The two deeper carbonates (stage III development) occur at depths of about 6-8 and 10 ft, respectively, and generally conform to swale topography. They thus likely indicate paleo-depths of moisture penetration as the swale episodically filled with colluvium.

The underlying bedrock is highly weathered, particularly along the almost-vertical foliation planes. No faults were recorded by the USCE in this section, nor were any seen extending through basal channel gravels into the overlying clayey colluvium.

The thick colluvium filling the Trench Site 6 swale cannot be definitely assigned to one of the regional Quaternary formations. However, an approximate age is deduced from the presence and depth of the carbonates: the upper diffuse carbonate probably reflects the Holocene soil-climatic regime; and the deeper, stage III accumulations most likely formed during "pluvial" epochs of the Pleistocene. Significantly, the modern swale axis does not conform with the paleo-swale axis (buried channel deposits); thus also suggesting great antiquity for this topographic feature. Accordingly, judging mainly from colluvial thickness, from geomorphic setting, and from occurrence of multiple, deep carbonates, the swale has probably been slowly filling for perhaps tens of thousands of years.

No faults were exposed in the Site 6 trench; and the swale-filling colluvium and carbonate markers are not offset. Hence, it is highly probable that at least this portion of the "County Line lineament" is not fault controlled, but rather reflects an ancient fluvially-incised channel now preserved as a linear, colluvial-filled swale.

SUMMARY AND CONCLUSIONS

The Corps of Engineers has excavated and logged trenches at six sites in Madera and Merced counties in order to determine the possible presence and age of faults near Hidden and Buchanan Dams. Two of the trench and roadcut sites investigated the possible presence of previously-inferred faults; and the other four sites assessed the origin of representative, northwest-trending photographic lineaments, features which abound in the eastern San Joaquin Valley and have been inferred to possibly be expressions of faults.

An approximate age for trench and roadcut-exposed sediments has been mainly deduced from soil-stratigraphic and geomorphic relationships; and the correlation of these sediments to the three major Quaternary formations in the San Joaquin Valley; namely, Modesto (youngest), Riverbank, and Turlock Lake.

Trench Site 1 exposed sediments in a large swale immediately north of the San Joaquin River. This swale, coincident with a prominent lineament, proved not to be of fault origin. Rather, unbroken deposits of Riverbank age were encountered; and these, judging from soil-stratigraphic and local geomorphic relations, are at least 125,000 years old.

Trench Site 2, the locality of a previously-inferred fault, likewise encountered no evidence for Quaternary tectonism. Here an apparent fault was found to be a Turlock Lake-age channel incised in older fluvial deposits; and all sediments were undisplaced.

Trench Site 3 exposed Modesto, Riverbank, and possibly even older Turlock Lake-age sediments within a linear swale defining part of a northwest-southeast lineament south of the Madera Canal. No faults were observed; and a strongly-developed paleosol is traced across the swale as an unbroken stratigraphic marker. This soil, based on relative profile development, is at least about 100,000 years old.

Trench Site 4, a backhoe-cleaned roadcut, exposed Riverbank-age sediments and capping relict paleosol, and underlying Turlock Lake deposits and associated buried paleosol. All sediments were unbroken, negating the presence of a postulated late Quaternary fault at this locality.

Trench Site 5 exposed swale-filling sediments coincident with a major northwest-trending lineament. Undisplaced Turlock Lake sediments and overlying swale-filling colluvium were undisplaced. Hence, here also there was no evidence for Quaternary-age faulting.

Trench Site 6 focused on the origin of a deep paleo-swale coincident with and forming part of the so-called "Merced-Mariposa County Line lineament." No faults were observed in either the thick, swale-filling clayey sediments or in the underlying metamorphic bedrock. A late Pleistocene age is esimated for the swale clay based mainly on the depth, morphology, and origin of three distinct carbonate zones.

In sum, no faults were encountered at any of the six USCE investigation sites. Two previously-inferred faults are now shown to be non-tectonic features. And four representative "lineament sites" are

likewise demonstrated to be not coincident with any observable Quaternary fault. It thus appears that most, if not all, of the northwest-trending lineaments recognized in Quaternary sediment in Madera and Merced counties originated as tributaries to major west-flowing streams. These sidestreams apparently were mainly incised in late Pleistocene time, ostensibly during "pluvial" epochs. The resultant channels are now generally preserved only as remnant linear swales which are slowly filling with colluvium. The USCE investigations show that, to date, no faults are known to disrupt Quaternary-age sediments in Madera and Merced counties and, therefore, to influence design of Hidden and Buchanan Dams.

REFERENCES CITED

Arkley, R. J., 1954, Soils of eastern Merced County: Univ. Calif., Agricultural Experiment Station Soil Survey, v. 11 174 p.

_____, 1962a, The geology, geomorphology, and soils of the San Joaquin Valley in the vicinity of the Merced River, California: in Geologic guide to the Merced Canyon and Yosemite Valley, California: Calif. Div. Mines and Geology Bull. 182, p. 25-31.

_____, 1962b, Soil Survey of the Merced area, California: U.S. Dept. Agriculture, Soil Survey Series 1950, no. 7, 131 p.

_____, 1963, Calculation of carbonate and water movement in soil from climatic data: Soil Science, v. 96, no. 4, p. 239-248.

Davis, S. N., and Hall, F. R., 1959, Water quality of eastern Stanislaus and northern Merced counties, California: Stanford University Pubs. in the Geological Sciences, v. 6, no. 1, 112 p.

Gile, L. F., Peterson, F. F., and Grossman, R. B., 1966, Morphological and genetic sequeces of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.

Hansen, R. O., and Begg, E. L., 1970, Age of Quaternary sediments and soils in the Sacramento area, California, by uranium and actinium series dating of vertebrate fossils: Earth and Planetary Science Letters, v. 8, no. 6, p. 411-419.

Harden, J. W., 1987, Soils developed in granitic alluvium near Merced, California: U.S. Geological Survey Bulletin 1590-A, 65 p.

Harlan Miller Tait, 1987, Photogeologic interpretation and imagery analysis, Hidden and Buchanan Dams Near Merced, California: Consultants' report (San Francisco) prepared for Sacramento District, Corps of Engineers, Project 437.05, Sept. 18, 1987, 53 p., appendix, plate.

Huntington, G. S., 1971, Soil survey, eastern Fresno area, California: U.S. Dept. Agriculture, Soil Conservation Service, 323 p., plates.

Janda, R. J., 1966, Pleistocene history and hydrology of the upper San Joaquin River, California: Berkeley, Univ. of California Ph.D. Dissertation, 425 p., plates.

_____, and Croft, M. G., 1967, The stratigraphic significance of a sequence of Noncalcic Brown soils formed on the Quaternary alluvium of the northeastern San Joaquin Valley, California; in Morrison, R. B., and Wright, H. E., (eds.), Quaternary soils: International Assoc. for Quaternary Research, VII Congress, Proceedings v. 9, p. 158-190.

Marchand, D. E., 1976a, Preliminary geologic maps showing Quaternary deposits of the southern Merced area, eastern San Joaquin Valley, Merced and Madera counties, California: U.S. Geological Survey Open-file Rept. 76-838, 12 p. scale 1:24,000, 7 sheets.

_____, 1976b, Preliminary geologic maps showing Quaternary deposits of the Chowchilla area, eastern San Joaquin Valley, Merced and Madera counties, California: U.S. Geological Survey Open-file Rept. 76-839, 12 p., scale 1: 24,000, 5 sheets.

_____, 1976c, Preliminary geologic maps showing Quaternary deposits of the Daulton area, eastern San Joaquin Valley, Madera County, California: U.S. Geological Survey Open-file Rept. 76-840, 12 p., scale 1:24,000, 4 sheets.

_____, 1976d, Preliminary geologic maps showing Quaternary deposits of the Madera area, eastern San Joaquin Valley, Madera and Fresno counties, California: U.S. Geological Survey Open-file Rept. 76-841, 12 p., scale 1:24,000, 8 sheets.

_____, and Allwardt, A., 1970, Quaternary deposits, northeastern San Joaquin Valley, California: U.S. Geological Survey Map MF-945, scale 1:125,000.

_____, 1981, Late Cenozoic stratigraphic units in northeastern San Joaquin Valley, California: U.S. Geological Survey Bull. 170, 70 p.

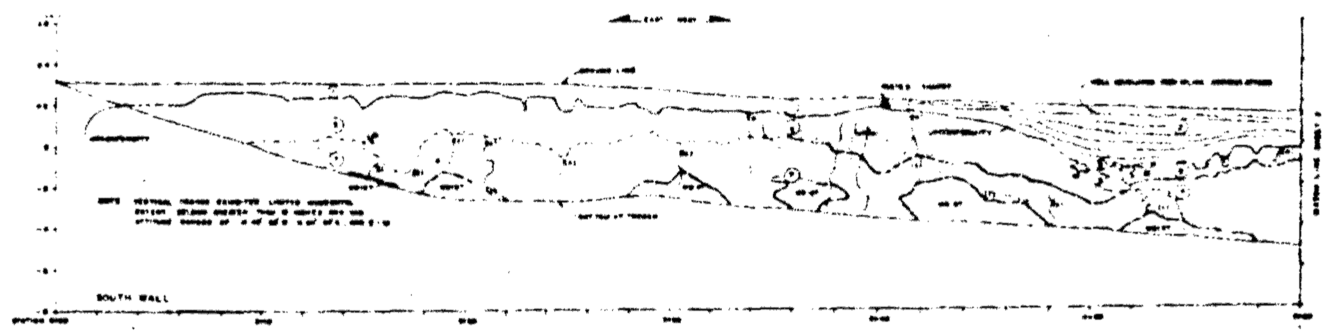
Rosholt, J. N., 1980, Uranium-trend dating of Quaternary sediments: U.S. Geological Survey Open-file Rept. 80-1087, 41 p.

Shlemon, R. J., 1967, Quaternary geology of northern Sacramento County, California: Geol. Society of Sacramento, Annual Field Trip Guidebook, 60 p.

_____, 1972, A model of Pleistocene landscape evolution: the lower American River area, California: Yearbook, Pacific Coast Geographers, v. 34, p. 61-86.

_____, 1985, Application of soil-stratigraphic techniques to engineering geology: Bulletin of the Association of Engineering Geologists, v. XXII, no. 2, p. 129-142.

Ulrich, R., and Stromberg, L. K., 1962, Soil survey of the Madera area, California: U.S. Dept. of Agriculture Soil Survey Series 1951, no. 11, 155 p.



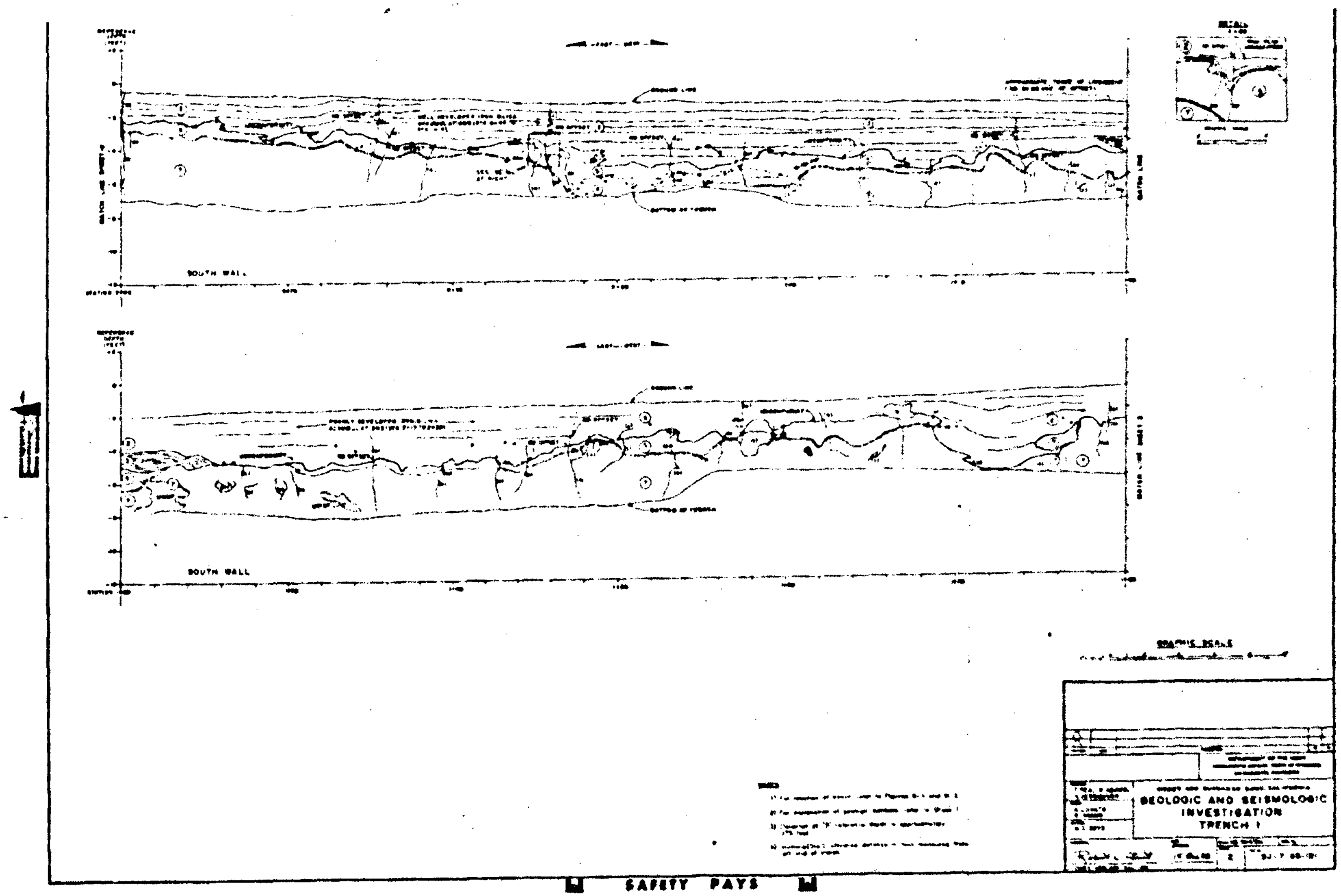
EXPLANATION

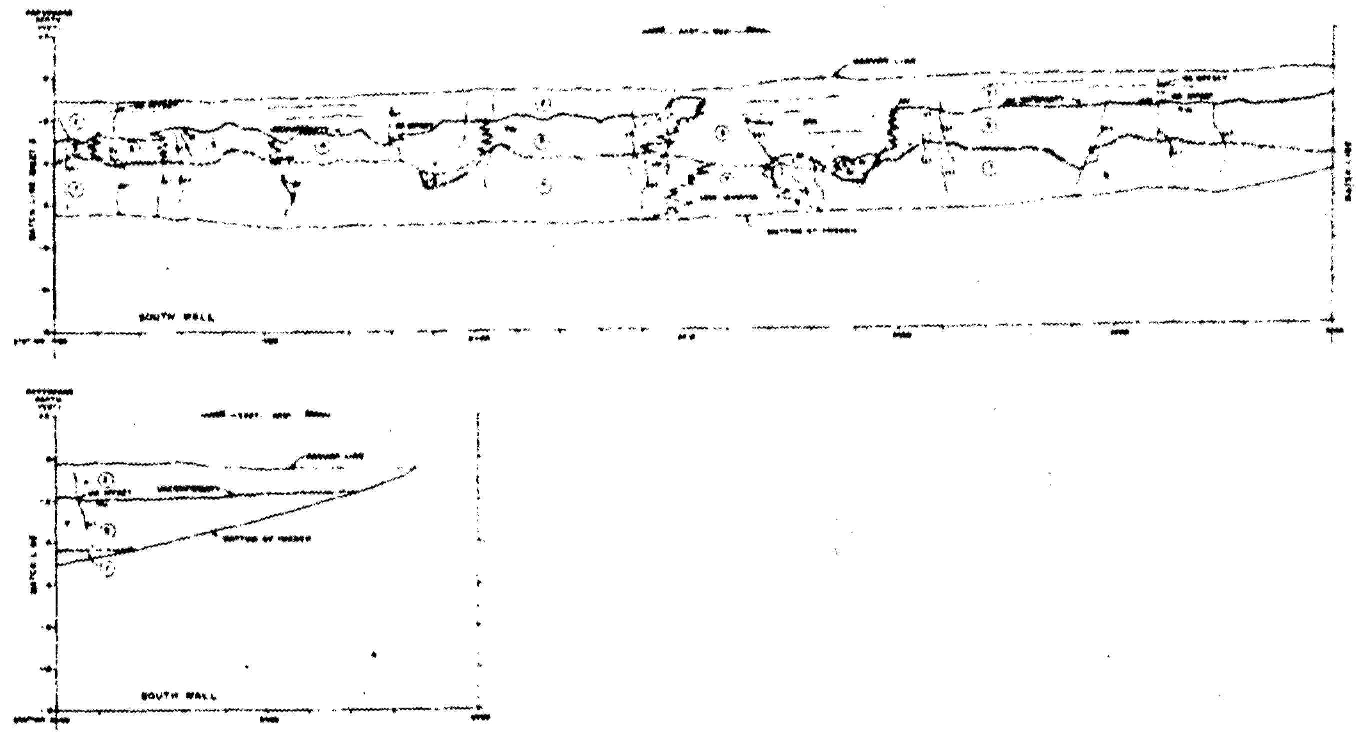
SYMBOLS

GRAPHIC SCALE

GEOLOGIC AND SEISMOLOGIC
INVESTIGATION
TRENCH 1

SAFETY PAYS

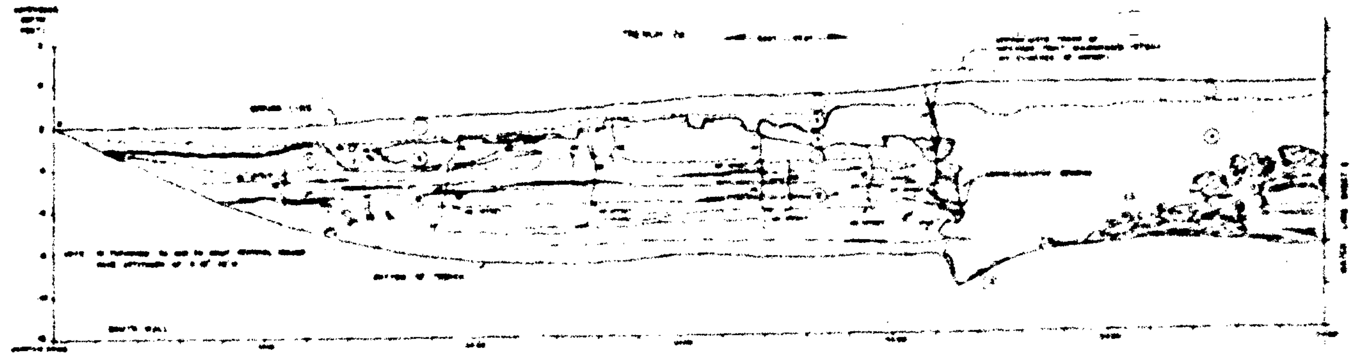

SOUTH WALL
SOUTH WALL
GEOLOGIC AND SEISMOLOGIC
INVESTIGATION
TRENCH 1
SAFETY PAYS



GRAPHIC SCALE

GEOLOGIC AND SEISMOLOGIC
INVESTIGATION
TRENCH 1

SAFETY PAYS

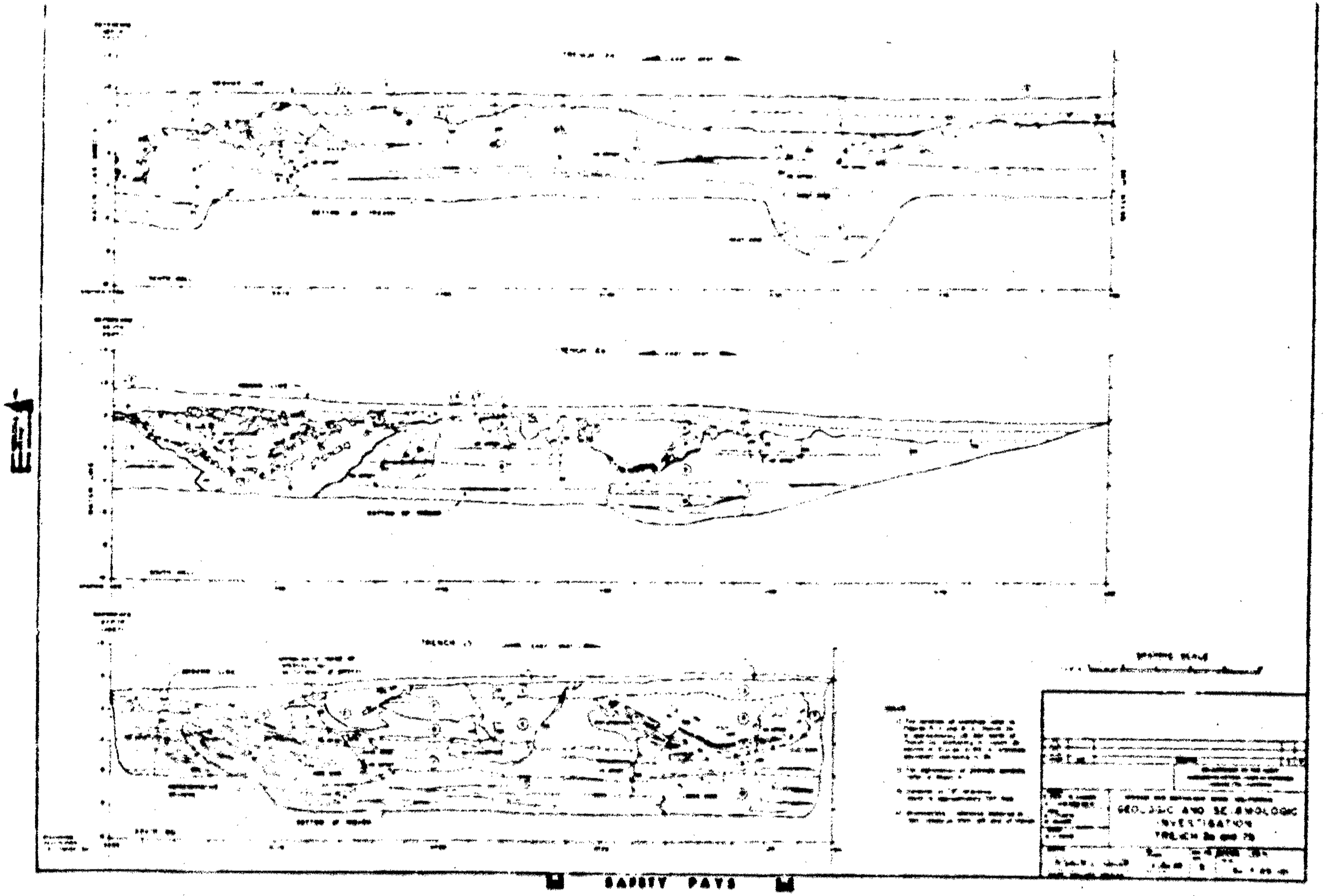


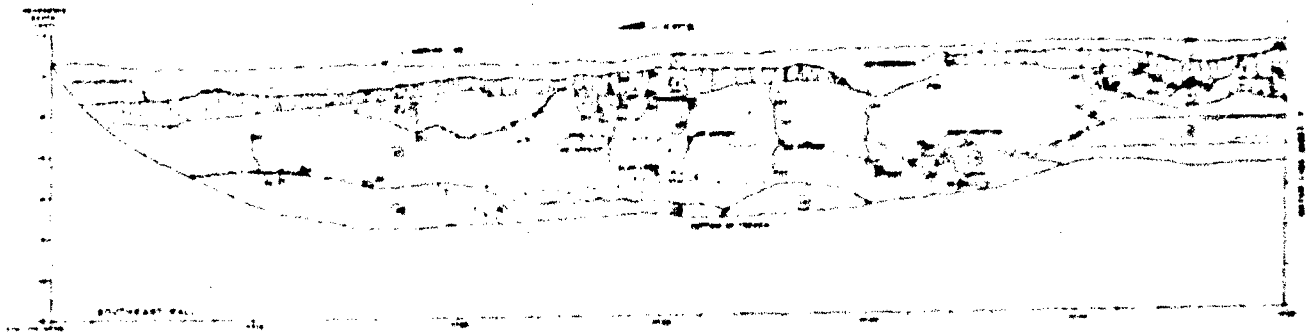
EXPLANATION

SYMBOLS

GEOLOGIC AND SEISMOLOGIC INVESTIGATION
TRENCH 2a and 2b

SAFETY PAYS


GEOLOGIC AND SEISMOLOGIC
INVESTIGATION
SAFETY PAYS



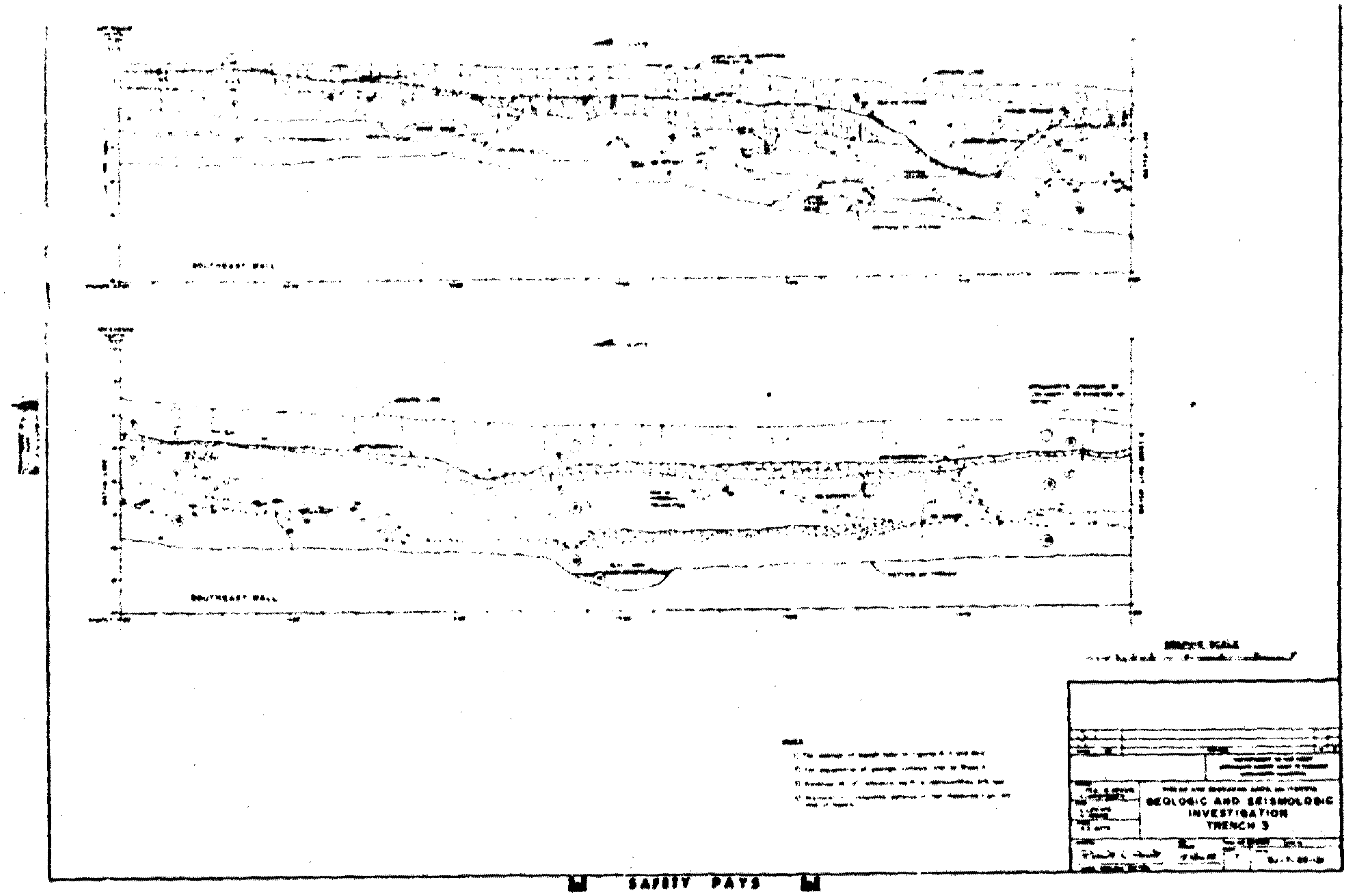
EXPLANATION

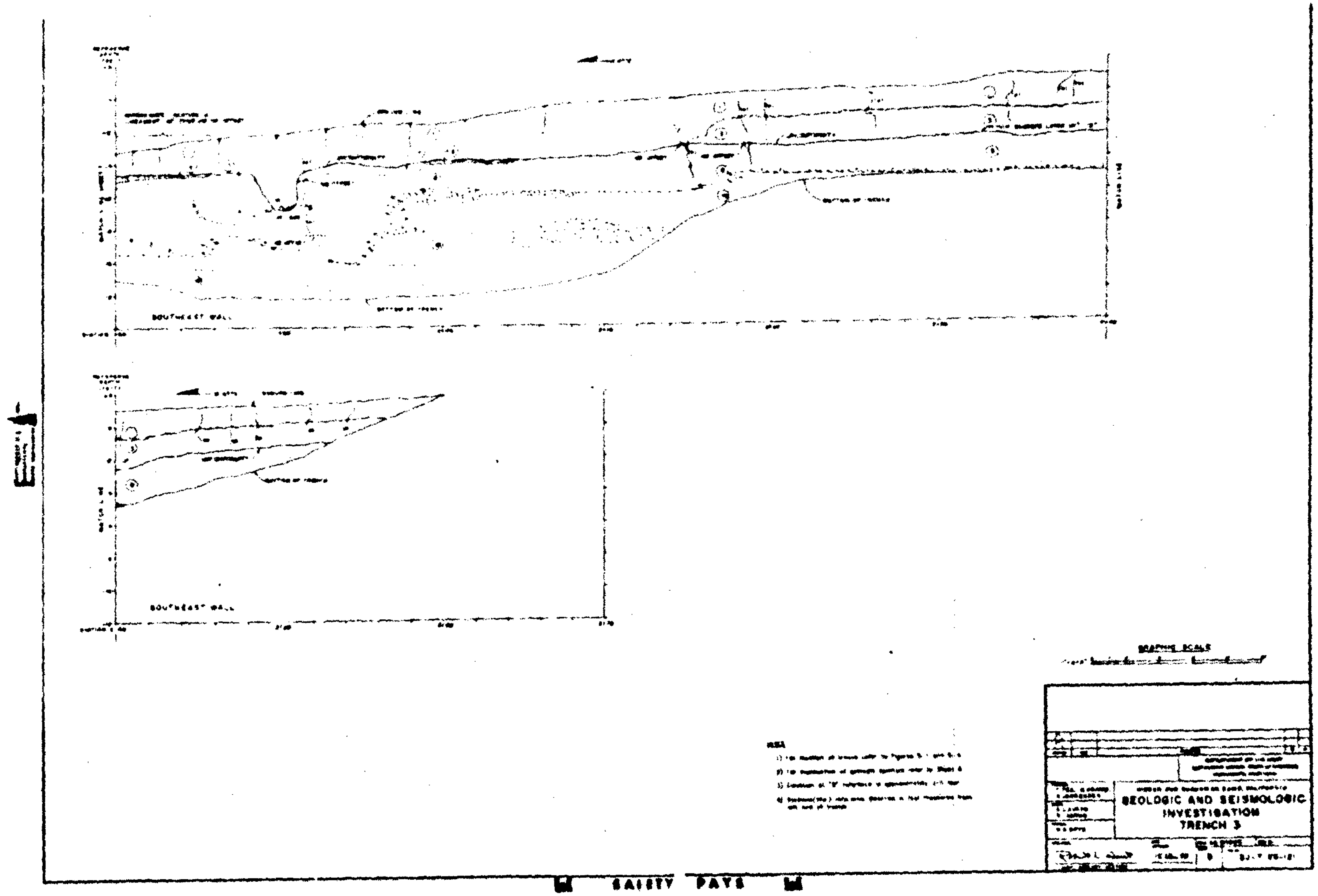
SYMBOLS

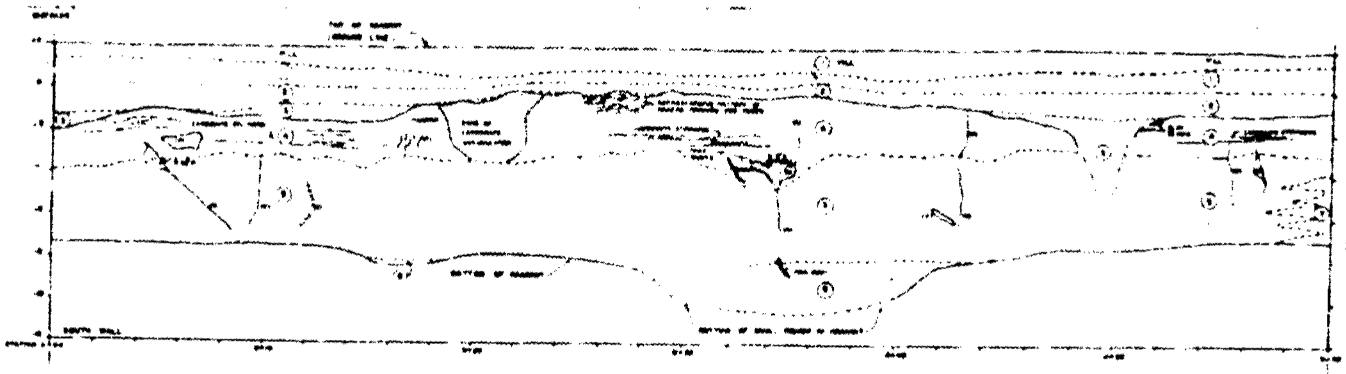
GRAPHIC SCALE

GEOLOGIC AND SEISMOLOGIC INVESTIGATION TRENCH 3

SAFETY PAYS


SOUTHEAST WALL
SOUTHEAST WALL
GEOLOGIC AND SEISMOLOGIC
INVESTIGATION
TRENCH 3
SAFETY PAYS


SOUTHEAST WALL
BOTTOM OF TRENCH
SOUTHEAST WALL
GRAPHIC SCALE
GEOLOGIC AND SEISMOLOGIC
INVESTIGATION
TRENCH 3
SAFETY PAYS

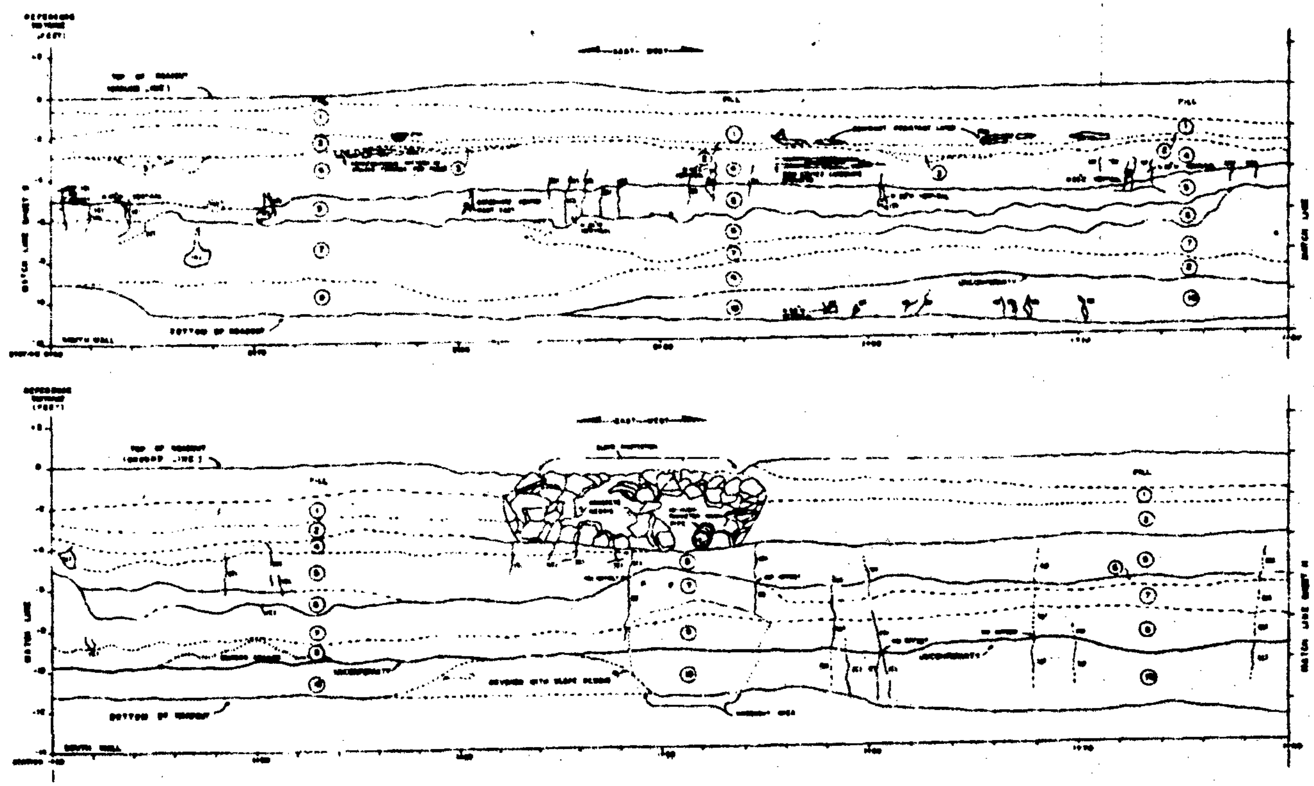


EXPLANATION

SYMBOLS

GEOLOGIC AND SEISMOLOGIC INVESTIGATION
RL ADOUT (SITE 4)

SAFETY PAYS

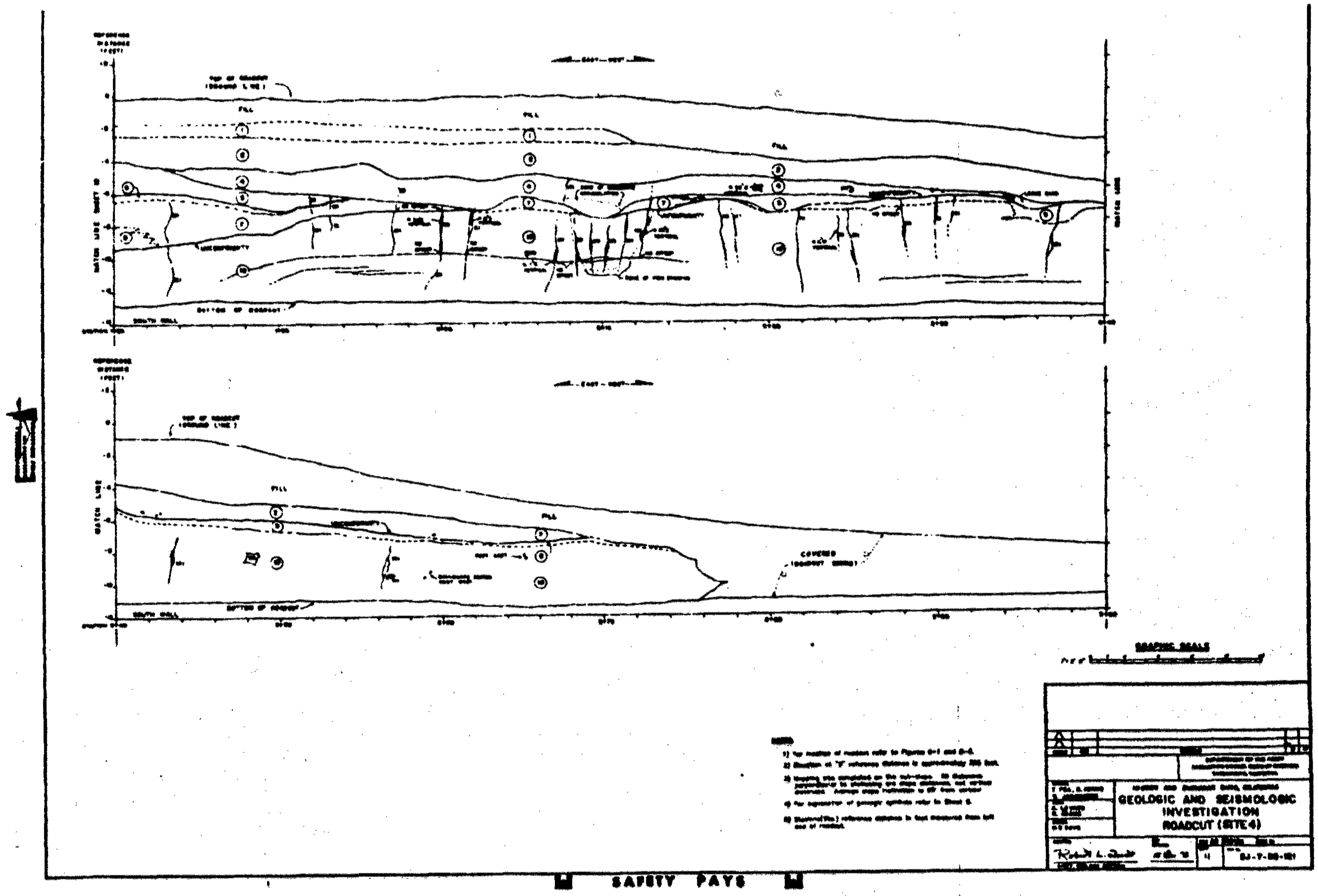


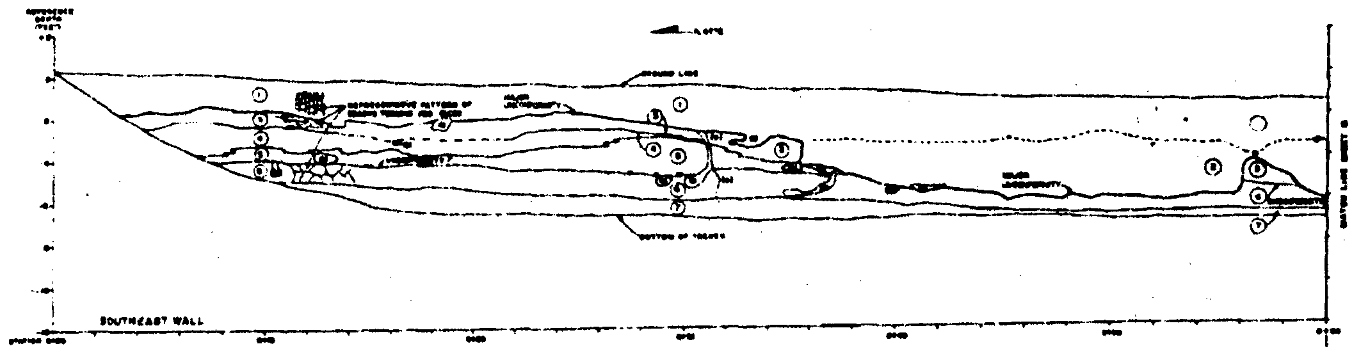
GRAPHIC SCALE

GEOLOGIC AND SEISMOLOGIC INVESTIGATION ROADCUT (SITE 4)

10

SAFETY PAYS


FILL
COVERED
GEOLOGIC AND SEISMOLOGIC
INVESTIGATION
ROADCUT (SITE 4)
SAFETY PAYS

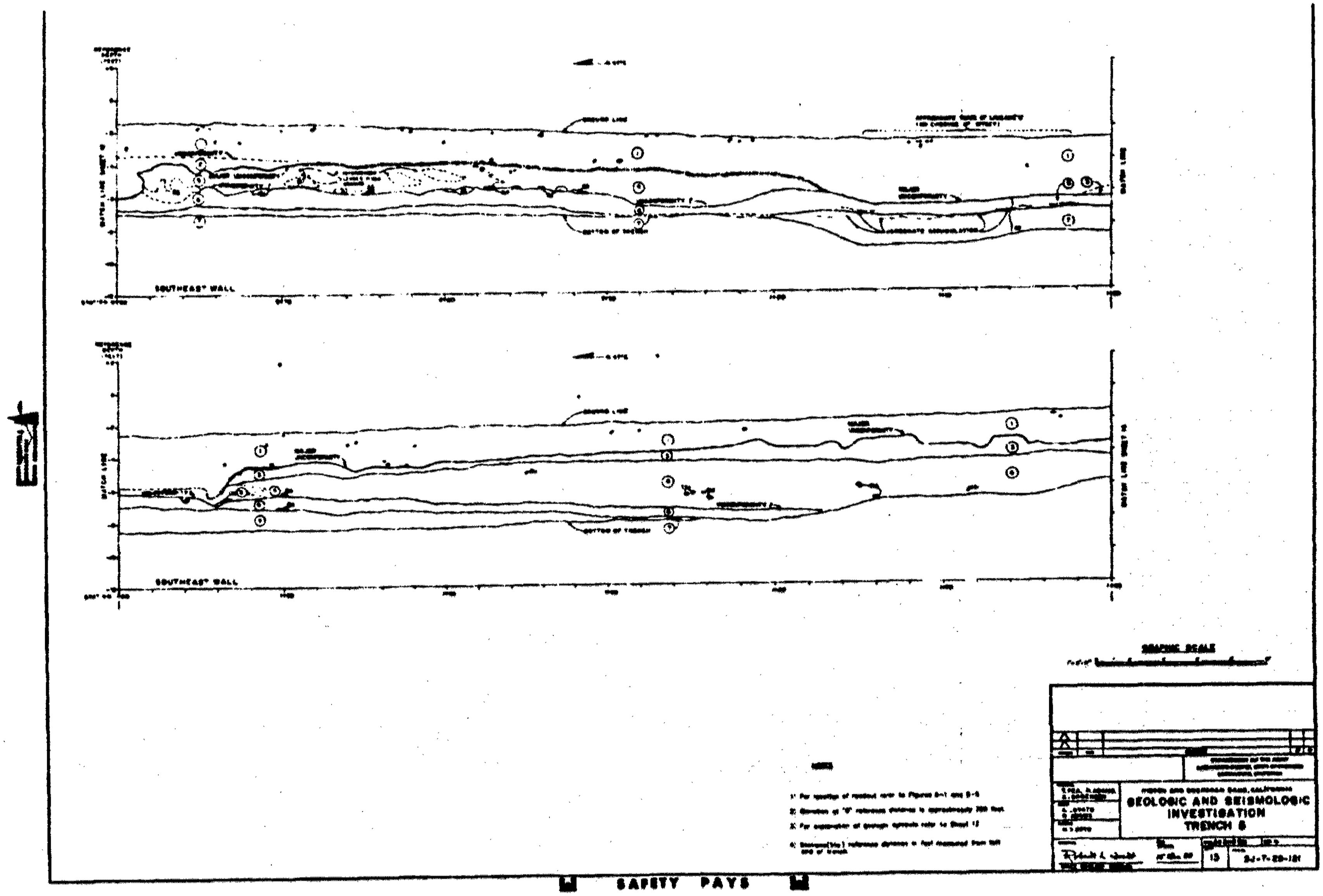


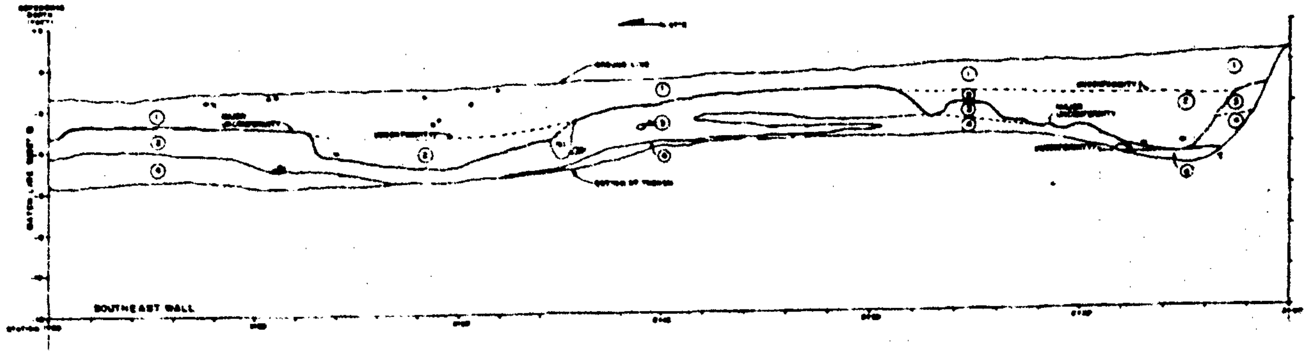
EXPLANATION

SYMBOLS

GEOLOGIC AND SEISMOLOGIC INVESTIGATION TRENCH B

SAFETY PAYS


SOUTHEAST WALL
SOUTHEAST WALL
GRAPHIC SCALE
GEOLOGIC AND SEISMOLOGIC
INVESTIGATION
TRENCH 6
13
SAFETY PAYS



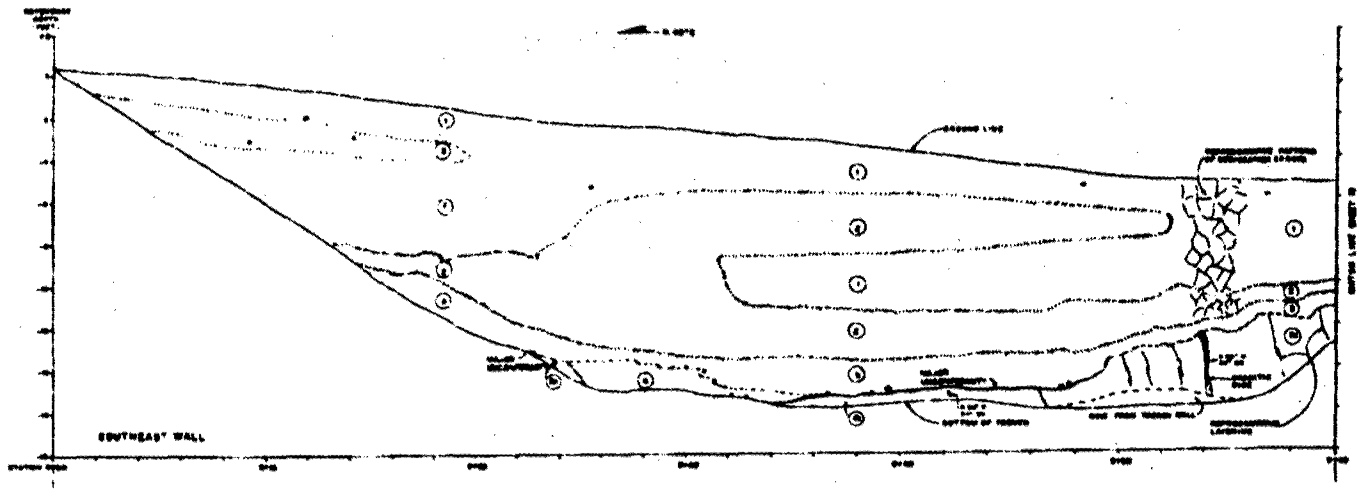
GRAPHIC SCALE

NOTES

1) For location of trench refer to Figures [illegible]
2) [illegible] approximately 300 feet.
3) For explanation of geologic symbols refer to Sheet [illegible]
4) Stations (Sta.) reference distance in feet measured from [illegible] end of trench.

GEOLOGIC AND SEISMOLOGIC INVESTIGATION
TRENCH 5

SAFETY PAYS

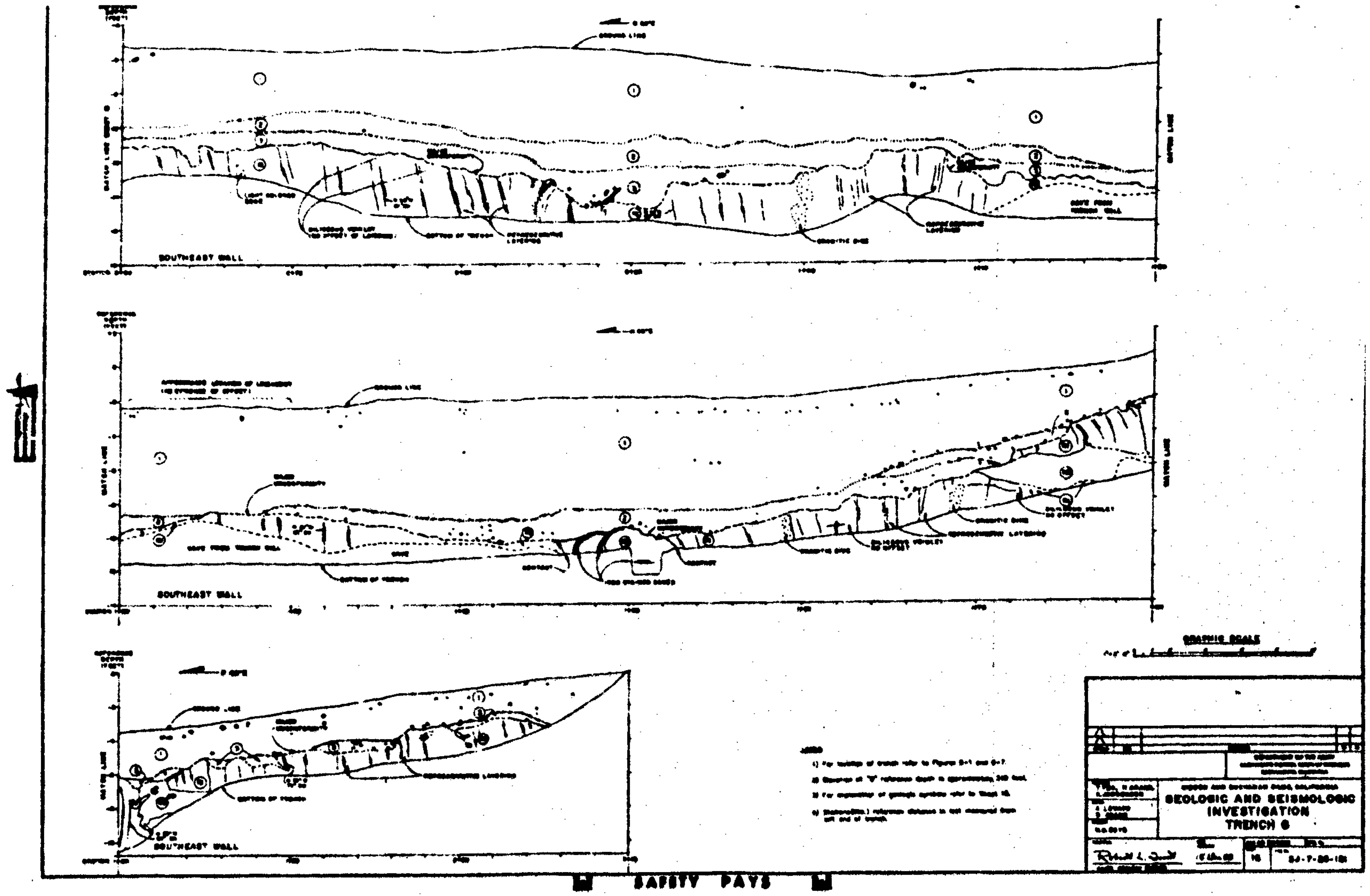


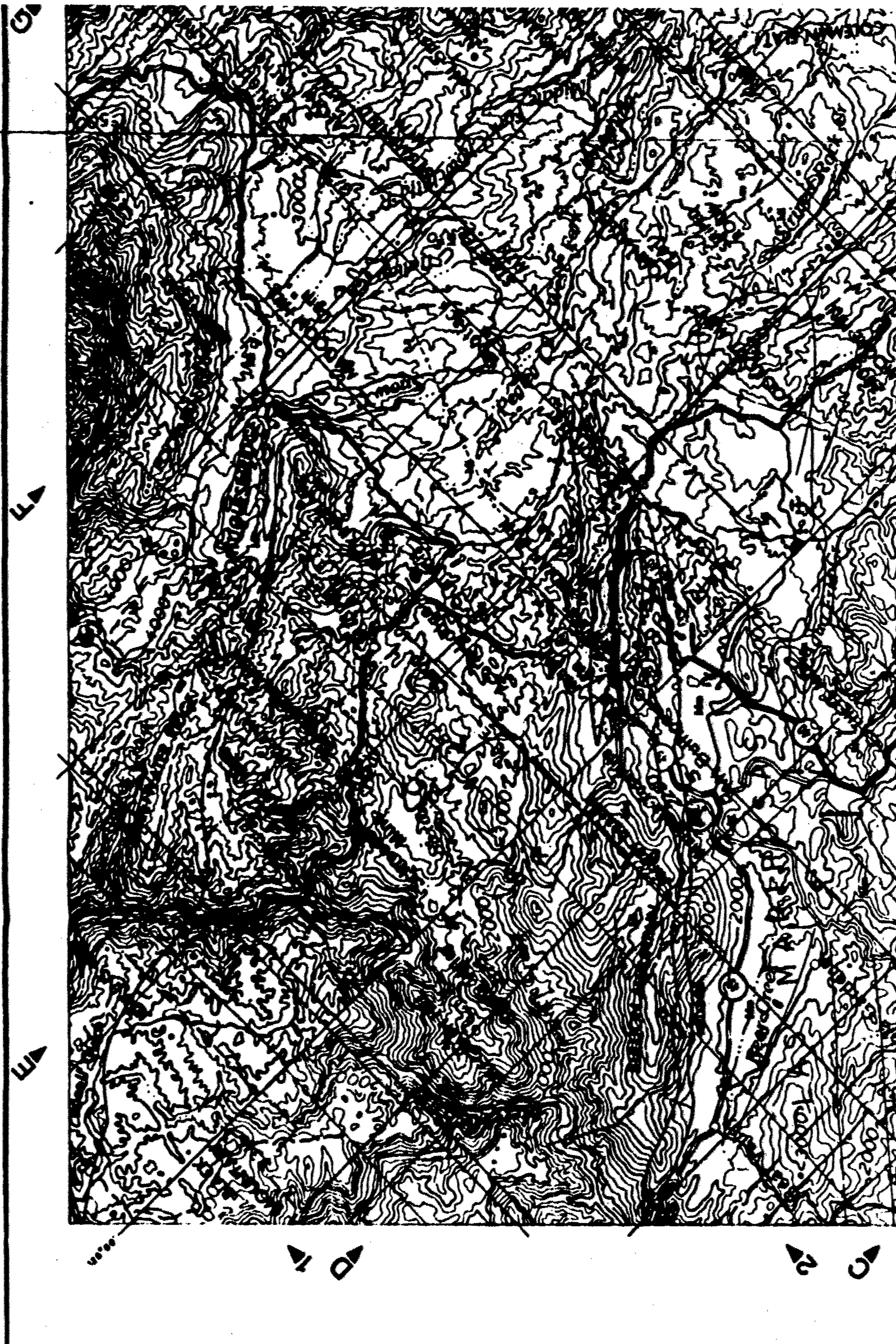
EXPLANATION

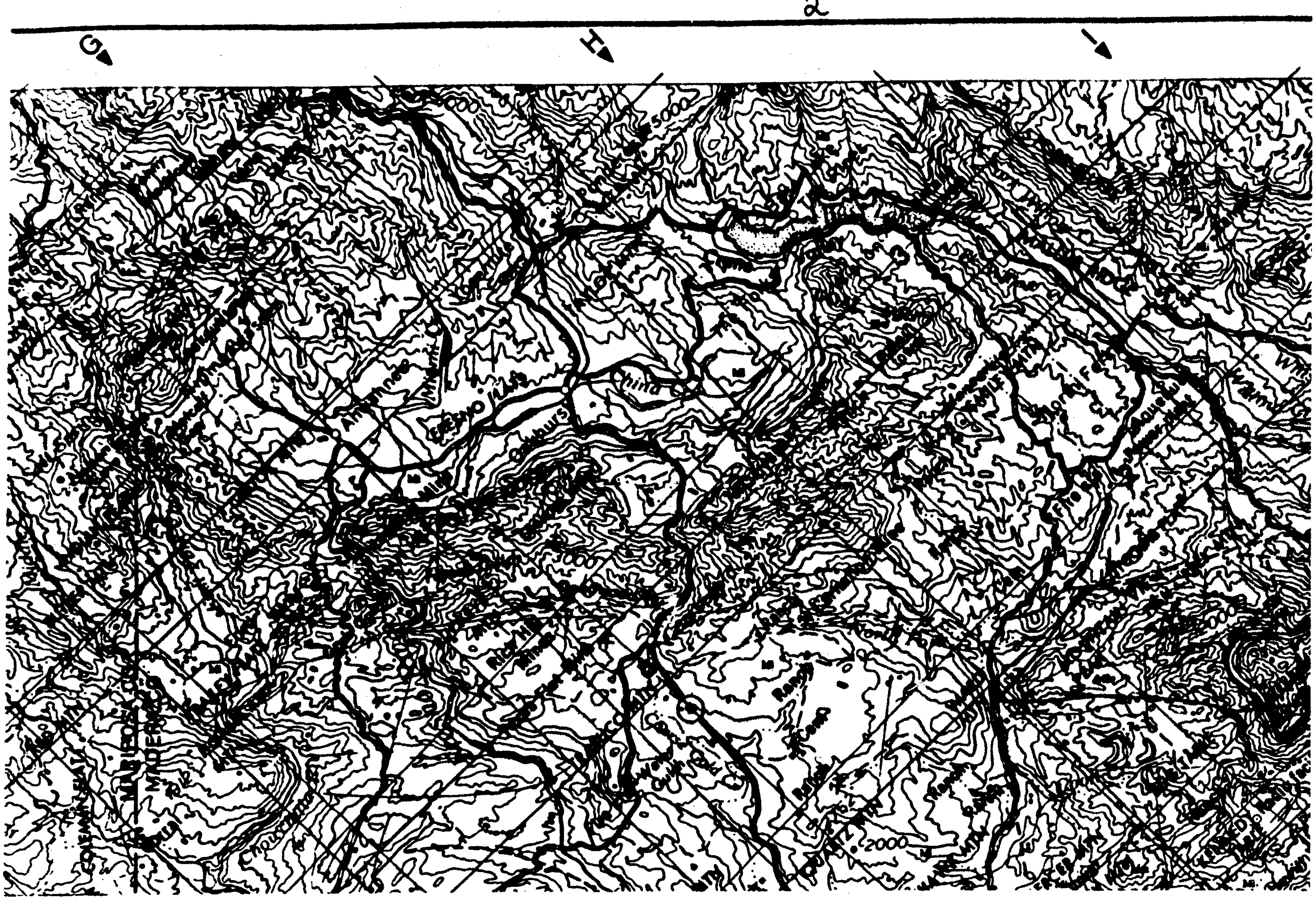
SYMBOLS

GEOLOGIC AND SEISMOLOGIC INVESTIGATION
TRENCH 8

SAFETY PAYS


SOUTHEAST WALL
SOUTHEAST WALL
SOUTHEAST WALL
GRAPHIC SCALE
GEOLOGIC AND SEISMOLOGIC
INVESTIGATION
TRENCH 6
SAFETY PAYS




2
G
H
I

3

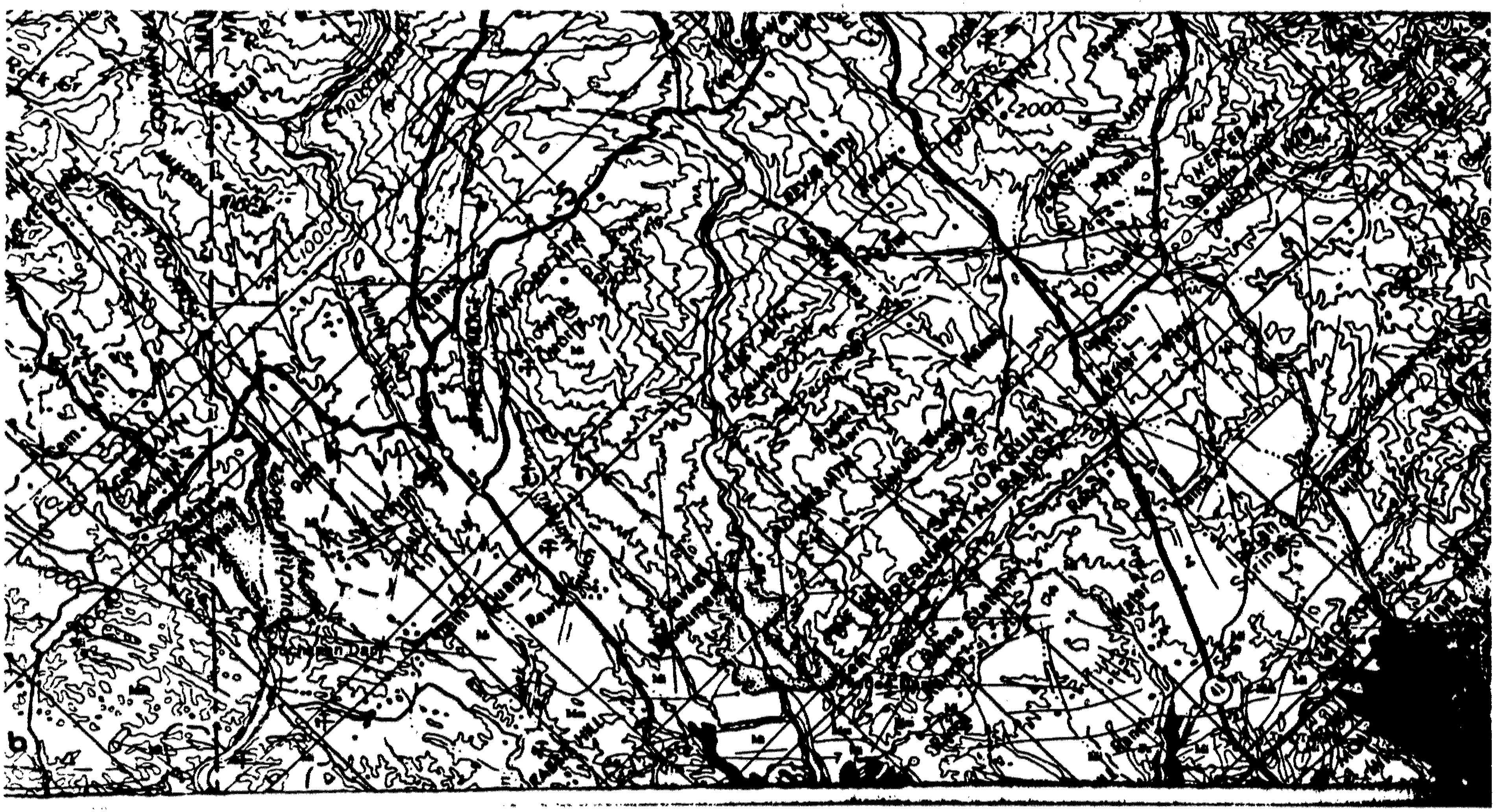
EXPLANATION

DESCRIPTION OF MAP UNITS

Era	Map unit	Description
QUATERNARY		MODESTO FORMATION/ALLUVIUM/DREDGE TAILINGS
QUATERNARY		RIVERBANK FORMATION
QUATERNARY		TURLOCK LAKE FORMATION
TERTIARY	QTn	NORTH MERCED GRAVEL
TERTIARY	QTl	LAGUNA FORMATION
TERTIARY	Tm	MEHRTEN FORMATION
TERTIARY	Ta	AUBERRY FORMATION
TERTIARY	Tv	VALLEY SPRINGS FORMATION
TERTIARY	Ti	IONE FORMATION
MESOZOIC	Mi	UNDIFFERENTIATED INTRUSIVE ROCKS
MESOZOIC	Mm	UNDIFFERENTIATED METAMORPHIC ROCKS

MAP SYMBOLS


3
B
C
2
Indian Gulch
Fire Canyon Station
White Rock Mill
16


SPRUCE RIDGE
SAN JOAQUIN RANGE
b

Mm UNDIFFERENTIATED METAMORPHIC ROCKS

MAP SYMBOLS

CONTACT

3 PHOTO LINEAMENT

2 ---? FAULT: Dashed where approximate; dotted where concealed; queried where inferred

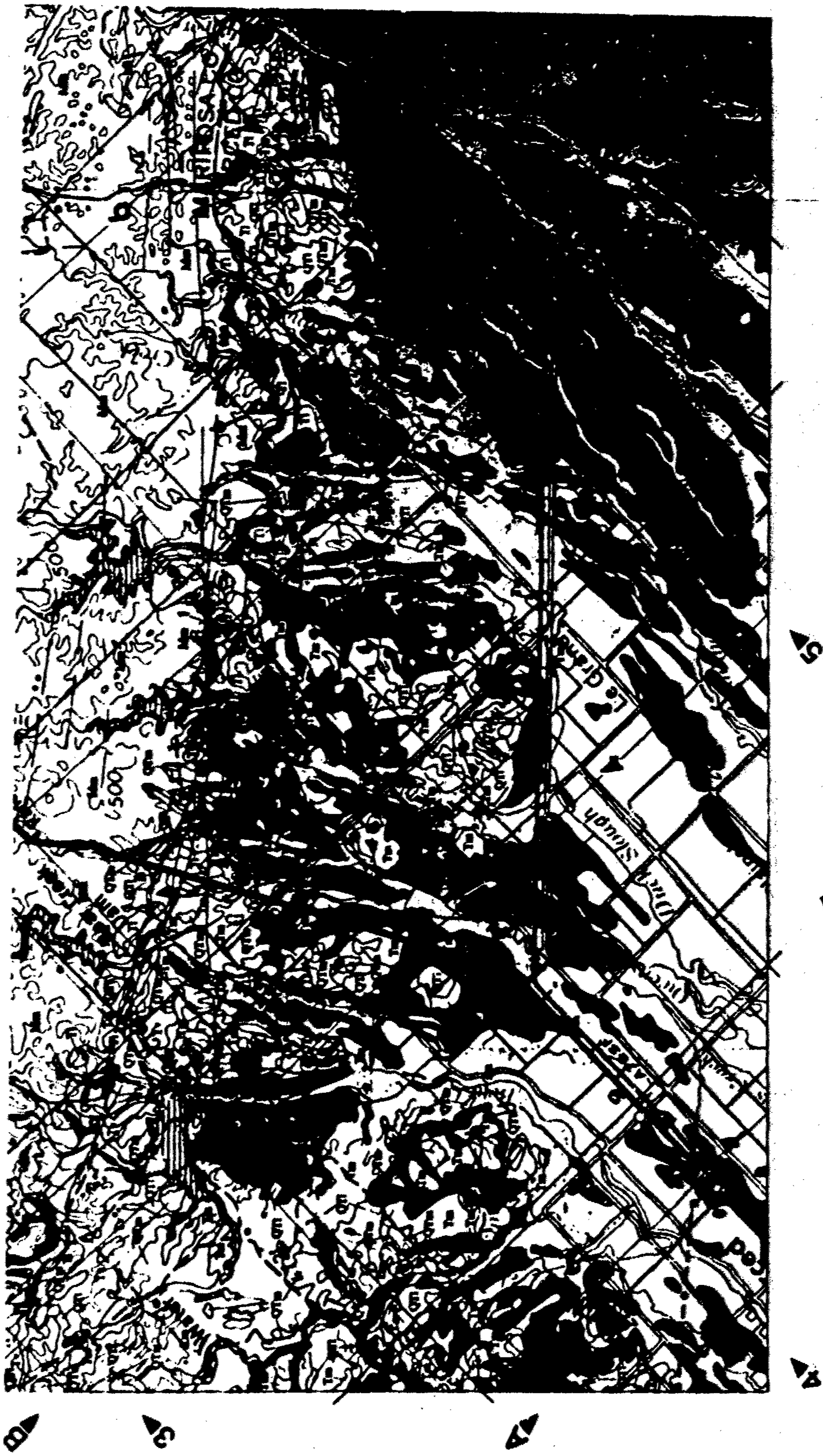
NOTES:

1. Topographic base map from enlargement of portions of U.S. Geological Survey, Fresno, Mariposa, Monterey, and San Jose, 1:250,000-scale topographic maps.

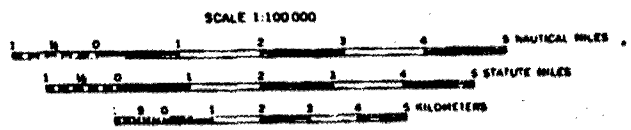
2. Specific lineaments and faults discussed in the accompanying report are numbered on this map consecutively within unique alpha-numeric grids which approximate the boundaries of USGS 7.5' quadrangles. Letters on the map margin define the grids in the north-south direction, while numbers on the map margin define the grids in the east-west direction.

3. The geologic and lineament data presented on this map were compiled from numerous sources referenced in the accompanying report. Because of differences in scale and quality of base maps of the original sources, and uncertainty in transferring, data shown on this map should be considered to be approximately located within limits of error of about 0.25± mile.

6



8



GEOLOGIC AND LINEAMENT MAP HIDDEN AND BUCHANAN DAMS Central California	Proj. No: 437.06 Date: 9/30/87 App'd by: RHW
Harlan Miller Tait	PLATE 1

Cartography by Michael Cusick. Photobase by Aqua Volop Inc. 8/87

8

9